VXH

Hedderwick

Presented to

Archibald M. Ferguson

Greenock 1865

VXH

A

TREATISE

ON

MARINE ARCHITECTURE,

CONTAINING THE

Theory and Practice of Shipbuilding,

WITH RULES FOR THE

PROPORTIONS OF MASTS, RIGGING, WEIGHT OF ANCHORS, &c.

INCLUDING

PRACTICAL GEOMETRY AND THE PRINCIPLES OF MECHANICS;

OBSERVATIONS ON

THE STRENGTH OF MATERIALS, HYDROSTATICS, &c.

WITH

MANY VALUABLE TABLES CALCULATED FOR THE USE
OF SHIPWRIGHTS AND SEAMEN;

ALSO

THE PROPORTIONS, SCANTLINGS, CONSTRUCTION, AND PROPELLING POWER

OF

STEAM-VESSELS.

ILLUSTRATED WITH TWENTY LARGE PLATES, CONTAINING PLANS AND DRAUGHTS
OF MERCHANT-VESSELS FROM FIFTY TO FIVE HUNDRED TONS, WITH MAST
AND RIGGING PLANS; PLANS AND SECTIONS OF A STEAM-BOAT
OF EIGHTY-HORSE POWER; AND EIGHT QUARTO
PLATES OF DIAGRAMS, &c.

BY

PETER HEDDERWICK.

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TO THE

SHIPOWNERS AND SHIPBUILDERS OF GREAT BRITAIN,

AND THE

SUBSCRIBERS FOR THIS WORK,

IN TESTIMONY OF HIS SENSE OF THEIR LIBERAL PATRONAGE,

THE FOLLOWING PAGES,

CONTAINING

THE RESULT OF MUCH LABOUR AND EXPERIENCE,

UNDERTAKEN SOLELY WITH A VIEW TO PRACTICAL UTILITY,

(WHICH CAN ONLY BE PROPERLY APPRECIATED BY PROFESSIONAL PERSONS),

ARE MOST RESPECTFULLY DEDICATED,

BY THEIR

MOST OBEDIENT AND VERY HUMBLE SERVANT,

THE AUTHOR.

PREFACE.

The Publications on Marine Architecture, though written by the most able men in the profession, have been hitherto almost entirely adapted to Ships of War, or Merchant-Vessels of the largest dimensions; while the smaller classes, by which the commerce of the different countries of Europe is chiefly carried on, have been greatly neglected. To remedy this defect, and supply the long-wished-for desideratum, this Work has been undertaken, for the advantage not only of the Practical Shipwright, but also of Owners, Masters, and others connected with Shipping.

In this work, the Theory and Practice of the Art are fully explained, and an original method or system of constructing the plans or draughts laid down, and applied to the actual plans of Merchant-Vessels; and several improvements on the Practical part of Shipbuilding are suggested. Also, for the advantage of Young Shipbuilders, or those whose practice has been confined to a particular class of vessels, the work contains the Working-plans of ten vessels from 50 to 500 tons, with Tables of Dimensions and Scantlings, &c. These plans have been taken from vessels of the most approved constructions, and which are known to possess the first-rate properties of merchant-ships.

From the long experience the Author has had as a Shipbuilder, and in superintending the equipment of vessels as a Surveyor, he has been enabled to include in this work several useful plans and proportions for the various parts of their outfit, amongst which will be found a plate and description of a Double-working Pump, which has been much approved of;—Observations on the Principles of Masting, with Rules for

calculating the dimensions of Masts for all the different class of shipping; also for the proportioning the Standing-rigging, Weight of Anchors, &c.; with several Tables calculated for the use of Shipwrights and Seamen; also a Treatise on the particular construction, proportions, and scantlings of Steam-Vessels, their propelling power, &c. illustrated by the plans, sections, &c. of a Steam-boat of eighty-horse power.

The avowed object of the following work *being practical utility*, the various subjects have been carefully written and arranged in the most simple and concise order, from the consideration of the first principles of Shipbuilding, to the launching and completing of the vessel. Every part has been correctly elucidated by Drawings on twenty large Plates bound up by themselves, and eight quarto Plates with this volume.

In preparing so large a work, without having the least assistance from any person excepting Mr. P. Hedderwick junior, who transferred several of the plates, and otherwise assisted, some slight errors may have crept in. These, however, it is hoped, will be overlooked by the Reader, to whom it will evidently appear, from the nature of the work, the closeness with which it is printed, and the construction of the plates, that it is truly original, and that no trouble or expense has been spared to render it worthy the notice of the Public.

LEITH, 12*th June* 1830.

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PART I.—INTRODUCTION.

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ERRATA.

Page 33, head-line, *for* PRACTICAL GEOMETRY, *read* MECHANICS.
— 63, line 33, *for* cube of the diameter, *read* square of the diameter.
— 85, — 29, *for* the strength which joins, *read* the straight line which joins.
— 102, — 23, *for* Edinburgh, Glasgow, Leith, and London, *read* London, Leith, Edinburgh, and Glasgow.
— 143, — 10, *for* stern, *read* stem.
— 157, — 39, *for* in the middle, *read* at the ends than 5-7ths of their mouldings at the middle.
— 184, — 19, *for* knee, *read* keel.
— 203, — 18, *for* Plate XIV. *read* Plate XXIV.
— 305, — 35, *for* half its diameter, *read* its whole diameter.
— 385, — 6, *for* height of the vessel, *read* weight of the vessel.

MARINE ARCHITECTURE,

PART I.

INTRODUCTION,

CONTAINING

PRACTICAL GEOMETRY, MECHANICS, STRENGTH OF MATERIALS, HYDROSTATICS, AND HYDRAULICS.

CHAPTER I.

THE object of the following Treatise is to explain, in an easy manner, the Theory and Practice of Marine Architecture—to put into the hands of the young or inexperienced Shipbuilder such information as his particular situation requires, with proper working plans of Merchant Vessels, of the best general Proportions and most approved Constructions, for his guidance—the methods of calculating the dimensions of Masts, Yards, Rigging, Anchors, &c.

The reader need not expect to find in this work, an Historical Account of the Rise and Progress of the Art of Shipbuilding, which is in some respects interesting *only* to those persons who laudably pursue the study of this Science with a view to acquiring general information, and would be of no advantage in our principal design, *i. e. practical utility*; and as this will be best promoted by divesting our several subjects as much as possible of useless speculation, the Author has declined entering into laboured examinations of the various Theories that have from time to time been proposed, for the cultivation of Naval Architecture.

It is almost unnecessary to insist upon the Shipbuilder combining a knowledge of the theoretical with the practical branch of his business: individuals of the most eminent talents have already insisted upon this with great propriety—not an entirely abstract Theory; for, as Mr. Harvey distinctly states, that much may indeed be said about Theory; but pure Theory has yet done but little for Shipbuilding—what we

want is a Theory founded on the basis of experiment and observation. For without this no Theorist need pretend to the mastery of Shipbuilding; without practical experience, his notions on the subject will, for the most part, be only useless and chimerical. On the other hand, although a person having but little knowledge of the theory or principles of Mechanics may be able to carry on in his accustomed practice with tolerable advantage, yet he is equally unable to carry on Shipbuilding to its full extent. Give him a vessel on a new construction, or out of his accustomed routine of dimensions, and he is comparatively lost; his ideas are in a great measure limited to his immediate practice, and he is unable to form an estimate of the effect of new inventions or proposed improvements. For although trial and experiment is the only sure test, which will either disclose their absurdities or prove their advantages, yet by a cool investigation of the principles of any proposed theory or improvement, we may be enabled to form some near conception of its ultimate success.

The acquirements which the young Shipwright should possess, previous to entering into a consideration of the theory and practice of Marine Architecture, should no doubt be as extensive as his circumstances will allow; but if he has a proper understanding of the fundamental principles of Arithmetic, Practical Geometry, Mechanics, Strength of Materials, Hydrostatics, &c. to which the true principles of Shipbuilding are consistent, it may be considered sufficient for what is required in general practice. In our opinion, the extensive course of instruction pursued at the College of Naval Architecture at Portsmouth is only necessary for those who are to be employed in constructing ships of war.

For the advantage of our young readers, we shall treat shortly on the above-mentioned subjects, with the exception of Arithmetic, by way of introduction to the other parts of the work.

If the reader has not previously been engaged in the construction of plans or draughts of Vessels, it will be necessary for him to describe the different geometrical figures with his compasses. In this way, he will learn to handle his instruments with facility, and gain a familiarity with the explanation of figures or drawings by letters of reference, and soon be able to comprehend those of a more complicated nature, which are unavoidably requisite in describing the curves and sections used in delineating working plans or draught of vessels.

Before explaining the terms employed in Geometry, I shall first notice a few signs or characters which may be employed as expressions for shortening operations; these will only be used where they will tend greatly to conciseness.

Explanation of Signs or Characters used in this Work.

The sign + *Plus*, or addition, implies that the numbers or quantities that follow it are to be added to that which immediately precedes it. Thus $4+2$ signifies that the 2 is to be added to the 4, and is read 4 *plus* 2.

The sign − *Minus*, or less, signifying subtraction, placed between two figures or quantities, denotes that the figure or quantity that follows it is to be subtracted from that which precedes it. Thus $4-2$ signifies that the 2 is to be taken from the 4, and is read 4 *minus* 2.

The sign × *Into*, or Multiplication, denotes that the numbers between which it is placed are to be multiplied together. Thus 4×2 indicates that the 4 is to be multiplied by 2.

The sign ÷ *By*, or Division, indicates that the number which precedes it is to be divided by that which follows it. Thus, 24÷8 denotes that the 24 is to be divided by 8. It is also expressed thus, $\frac{24}{8}$.

The sign = *Equality*, denotes that the two quantities between which it is placed are equal, as 4+6=8+2, as 4 adding 6 is equal to 8 adding 2, and so on.

Inequality is sometimes expressed thus, 4 > 2, indicating that 2 is less than 4, observing that the angular point is always next to the less quantity.

The signs of Proportion are, colons, and double colons, placed between the quantities. Thus 2 : 4 : : 8 : 16, or 3 : 5 : : 9 : 15, signifies that 2 is to 4 as 8 to 16; and that 3 is to 5 as 9 to 15, or $\frac{2}{4} = \frac{8}{16} = \frac{1}{2}$, and that $\frac{3}{5} = \frac{9}{15}$, and so on.

The Extraction of the Roots is expressed thus $\surd$, with a figure occasionally placed over it to indicate the degree of the power. Thus $\sqrt{4}$, signifies the square root of 4; $\sqrt[3]{27}$, the third or cubic root of 27; $\sqrt[4]{16}$, the fourth or biquadrate root of 16.

Explanation of the General Terms used in Geometry.

An Axiom—is a self-evident proposition, which requires no demonstration.

A Theorem—is a proposition to be demonstrated by fair reasoning.

A Problem—is something proposed to be done.

A Lemma—is a proposition premised, in order to facilitate a following demonstration.

A Proposition—is something proposed to be done.

A Corollary—is a necessary consequence, deducible from a proposition already demonstrated.

A Scholium—is an explanatory remark, or something that has been deduced from the preceding proposition.

An Hypothesis—is something supposed or premised in a proposition, and from which some certain consequences are deduced.

A Postulate—is something to be granted and agreed to.

PRACTICAL GEOMETRY.

The term Geometry is applied to the science which considers the properties of right or curved lines and angles, as formed according to certain laws,—the construction of all sorts of figures, by means of which the affections and measures of every form that possesses real magnitude are demonstrated.

It is divided into two parts, the Theoretical and Practical. The Theory of Geometry considers the relations, positions, and properties of lines,—thereby rendering a proposition clear to the understanding, without applying actual measurements—demonstrating, by a continuous chain of reasoning, deduced from principles previously established and confirmed by actual facts, which are laid down as maxims, from which are obtained the data or proof of every succeeding proposition. Practical Geometry consists in constructing lines or figures which are required for the regulation of plans, &c. It is to this part we shall direct attention, by shewing the methods of drawing

lines parallel and perpendicular to each other, and to construct a few curves, which may be useful in drawing the working plans of vessels. But it is unnecessary to enter into the reasoning from which these methods are deduced, as the Elements of Euclid are to be found in the hands of every one who has the slightest pretensions to mathematical knowledge.

The Reader will be pleased to observe that the Plates from No. 1 to 8, containing the figures herein referred to, are bound up at the end of this volume; the other large Plates are in the portfolio which accompanies it.

PROBLEM 1.—*To make an angle at a given point* E, (Plate I. Fig. 1), *on a straight line* E F, *equal to another angle* A B C.

From the centres B and E, with any radius, describe the arcs o and o'; take the distance $p\,q$ in the compasses, and with the point r on the line E F, describe the arc x; draw the line x E, then will the angle x E F be equal to the angle A B C.

PROBLEM 2.—*To bisect a given angle* A B C, (Plate I. Fig. 2), *that is, to divide it into two equal parts.*

From the centre B, with any radius as B h, describe the arc J h, and on the sides of the triangle A B and C B, where they are intersected by the arc J h, describe other arcs intersecting each other in D; join D B, and it will bisect the angle A B C as required.

PROBLEM 3.—*At a given distance from a straight line* A B, (Plate I. Fig. 3), *to draw another right line parallel to it.*

On the given straight line take any two points, g and c; on these points as centres, with the given distance in the compasses, describe the arcs x and x', draw a right line touching these arcs as tangents, and it will be parallel to the given line A B as required.

PROBLEM 4.—*To bisect or quadrisect a given angle* A B C, (Plate I. Fig. 4.)

Through any point C, draw the right line C D E, exactly parallel to B A; make C D = to C B; draw D B, which will bisect the angle; and if D E be made equal to D B, the line E B will quadrisect the given angle A B C.

PROBLEM 5.—*To bisect a given line* A B, (Plate I. Fig. 5), *by a perpendicular.*

From the point A and B as centres, and with any distance in the compasses greater than half A B, describe arcs intersecting in C and D; join the line between C and D, and it will bisect A B perpendicularly.

PROBLEM 6.—*From a given point* C, (Plate I. Fig. 6), *to erect a perpendicular.*

On the given line A B make any two points for centres equally distant from C, and with any equal radii greater than half the distance between the points; describe arcs intersecting in D; join D C, and it will be the perpendicular to A B as required.

Problem 7.—*To erect a perpendicular from a given point* B, (Plate I. Fig. 7), *on the end of a given line* A B.

From any point *x* as a centre, and with radius *x* B in the compasses, describe a semicircle cutting the given line in B and A; then draw the diameter or line A *x r*, and from the point *r* let fall the line *r* B, and it will be the perpendicular required.

Problem 8.—*To divide a given line* A B (Plate I. Fig. 8) *into any number of equal parts.*

Draw any right line as A C, forming an angle with the given line, on A C; mark off as many equal parts as the line A B is to be divided into; join the extreme part or division C, with the point B; then draw lines from each of the divisions in A C to A B all parallel to C B, and they will cut A B into the proposed number of equal parts.

Another method, without drawing parallel lines.—Thus let A B (*Fig.* 9) be the line that is to be divided into any number of equal parts, through one extremity; draw the line A C as before, on which set off the number of equal parts, which suppose 10, with any distance in the compasses as A 1; turn them eleven times over on the line A C; join C B, and produce it until the prolongation B D is equal to C B from the 9th division; join 9 D to cut A B in the point F, and F B will be 1-10th of A B; consequently distances equal to F B will divide A B into ten equal parts.

Problem 9.—*To find the centre of a given circle.*

Draw any line A B (*Plate* I. *Fig.* 10) as a chord; bisect it perpendicularly with the line D C, which will be a diameter; then bisect the diameter in the point *o*, which will be the centre of the circle as desired.

Problem 10.—*To describe a circle, the circumference of which shall pass through three given points.*

Let A B C (*Plate* I. *Fig.* 11) be the three given points; join A B and B C chords to the arc A B and C B; bisect these chords by right lines, and these lines will intersect in the point *o*, which is the centre sought; then on the same, and distance *o* A, or *o* C, describe a circle, and it will pass through the three points as required.

Problem 11.—*On a given chord* A B (Plate I. Fig. 12) *to describe an arc of a circle by a mechanical method.*

Place two rulers forming an angle A C B; fix them in C; place two pins at the extremity of the chord; hold a pencil in C; then move the edges of the rulers against the pins at the ends of the chord, and the point C will describe the portion of the circle required.

Problem 12.—*The circumference of a circle may also be described by a similar method,* (Plate I. Fig. 13.)

Place two rulers cross-ways, touching the three given points A B C; fix them by a

pin and by a transverse piece T; hold a pencil in A, and describe the arc B A C as before; then on the arc thus described, stick two pins P and P′ equal to the chord B C; reverse the instrument, and move it against the pins P P′, and so describe the lower portion of the circle B D C.

Problem 13.—*In a given circle, to describe any regular polygon.*

Draw the line A B (*Plate* I. *Fig.* 14) passing through the centre O, with the radii A O, and centres A and B; describe an arc cutting the circle in C and D; again, on these intersections, describe arcs E and F, intersecting in G; (the whole diameter A B may be taken and swept from A and B, and also meet or intersect in G); next divide the diameter A B into the same number of equal parts as the polygon is to have sides; draw the right line G H, passing in every case through the second division, then will the chord A H be the length of the side of the polygon; turn this distance round the circle; draw straight lines from point to point, and the polygon will then be completed.

This method, although not mathematically correct, is well suited to practice.

Problem 14.—*To cut off from a given line* A B (Plate I. Fig. 15) *any short or proportional part.*

Suppose it is required to find the 1-12th, 2-12th, or 3-12th parts of the line A B, erect the perpendicular B C, and at the point A erect A D exactly parallel to B C; draw D C parallel to A B; divide the height B C and A D into 12 equal parts, as 1, 2, &c. Join these points by lines which will be parallel to A B; next draw the diagonal B D, and it will intersect the parallel lines, so that if perpendiculars were let fall from their points of intersection, they would divide the line A B into 12 equal parts; consequently the distance 1 *e*, measured from the perpendicular BC, is 1-12th of A B, 2 *a* is 2-12ths, and so on. In like manner, any short line, as A B, may be divided into any number of equal parts, and measured off correctly, which could not be done by simply dividing any small distance as A B with compasses. Accordingly, on this principle, diagonal scales of various descriptions may be constructed.

Problem 15.—*To construct the common diagonal scales of feet and inches.*

Draw any straight line, as A B, (*Plate* I. *Fig.* 16) of such length as the magnitude of your intended plan may require, or the compasses will measure accurately. At any convenient distance above A B, draw another line exactly parallel to it, as C D, for the breadth of the scale; erect a perpendicular on the point A; take the distance you intend to represent a foot; mark it regularly along on the line A B, numbering the points 1, 2, 3, and reserving the first division from A to be divided into inches; on each of these divisions, draw up perpendicular lines, which will divide the length of the scale into feet; then divide the breadth of the scale into 6 equal parts, by drawing lines parallel to A B; bisect C F in the point 6; draw the diagonal A 6 and E 6, and the scale is completed. One example will illustrate it:—Suppose it is required to measure off 4 feet 4 inches from this scale, place one of the points of the compasses

on the 4th perpendicular line where it is cut by the 4th parallel line to A B; extend the other point to where this last line is cut by the diagonal 6 E, and it is the distance as required.

The divisions for the feet are varied, made greater or less, according to the magnitude of the object, whose several parts are to be accurately measured on the plan, or the size it is to be represented on the paper; when the divisions are made equal to 1-4th of an inch, it is considered a fair working scale. Small vessels have their plans drawn on a scale of 1-3d of an inch to the foot. Vessels of about 200 or 300 tons are commonly drawn on the quarter scale; and very large vessels, of 600 tons or upwards, on 1-6th of an inch to the foot.

Figures A, B, and C are also scales of feet and inches, A having four parallel lines in the breadth, B having three, and C two parallel lines,—the diagonal lines which divide the foot into inches being made to correspond.

Problem 16.—*To construct a decimal diagonal scale.*

Draw the parallel lines A B and C D (*Plate* I. *Fig.* 17); also the vertical lines for the divisions, 1, 2, 3, &c. for the feet; divide A C into 10 equal parts; draw lines at each of these divisions along the scale, parallel to C D and each other; divide A E and C F into 10 equal parts; draw from the first division on A E to the point F on C D; continue to join 2, 1; 3, 2; 4, 3; and so on, and the scale will be completed. Now, by the former plan of dividing a very short line into a number of parts, we have each 10th part of the distance A E divided into 10 equal parts, and as there are also 10 divisions in E F, we have $10\times10=100$, so that from this scale may be taken the 100th part of a foot.

Problem 17.—*To reduce or enlarge a simple rectilineal figure.*

Make any point P (*Plate* I. *Fig.* 18) in the given figure; from the point P, draw lines to all the corners of the figure A B C D, &c.; measure from P on these lines, the proportional distances taken from any scale of equal parts, according as the figure is to be larger or smaller than the original; then draw lines through all the points thus found, and the figure will be completed as represented by the dotted lines, the sides of the small figure being parallel to their respective sides of the larger. Figures may also be reduced or enlarged by drawing a number of squares over the original, and constituting the same number of squares, either larger or smaller, as it may be desired either to enlarge or reduce the copy; then by observing what squares certain parts of the drawing intersects, and making the copy to pass through the corresponding ones, the figure may be very accurately traced.

When very complex figures or drawings are to be reduced or enlarged, an instrument called the Pentograph, or a pair of proportioning compasses, are generally used.

Construction of Curves.

Having explained the methods of drawing lines parallel and perpendicular to each other, of constructing diagonal scales, &c. we shall next proceed to the construction

of a few Curves, as those formed by the sections of a cone, by the revolution of a circle when rolled on a plane, &c.

Definition.—A Cone is supposed to be a solid, the circumference of whose base is a circle, and having its sides bounded by straight lines, drawn from every part of the circumference of the base, to intersect each other in a point, vertical to the centre of the base, called the top or apex of the cone.

The cone is generated by the revolution of a right-angled triangle about one of its legs; and the leg on which it turns, or a line drawn from the centre of the base to the apex, is called the axis of the cone.

When the cone is cut by a plane passing through it, in five different directions, there are produced five different figures, that is to say, the periphery of these sections forms five different figures, each of which possesses properties peculiar to themselves, although in fact they are a system of regular curves naturally allied to each other.

If the cutting plane pass through the cone parallel to the base, the section is a circle.

If through the apex and any part of the base, the section is a triangle.

If the cutting plane pass obliquely through both sides of the cone, the section is an ellipse; or when it makes a less angle with the base A B, (*Plate* I. *Fig.* 19) than the side A C,—F G being the line of section.

If the cutting plane pass through the cone parallel to one of the sides, as *c d*, parallel to *a b*, (*Plate* I. *Fig.* 20), the section is called a parabola.

When the cutting plane makes a greater angle with the base than the side, or when it meets the opposite or inverted cone above (*Fig.* 21), the section is called a hyperbola.

The vertices of any section are the points where the cutting plane meets the opposite sides of the cone. The transverse axis is the line between the two vertices, and the middle point of the transverse is the centre of the conic section.

The conjugate axis is a line drawn through the centre perpendicular to the transverse.

Problem 18.—*To find the sections of a cone and right cylinder, according to Mr. Nicholson's method.*

Let A B C (*Plate* II. *Figs.* 34, 35, and 36) be the elevation of the cones, and D E the line of section, through the apex or top of the cone C. Draw C F parallel to the base A B, and produce F D to meet A B, produced to D; also to meet C F in F. On the base A B describe a semicircle equal to half the base of the cone. Divide this semicircle into any number of equal parts. Draw *d c* in *Fig.* 34, D *c* and D *c*, (*Figs.* 35 and 36), perpendicular to A B, D *d'* perpendicular to D F, also D *d'* perpendicular to D F, (*Figs.* 35 and 36.) From the points or divisions *a b c*, (*Figs.* 34, 35, and 36), draw lines cutting A B at right angles; and from the intersections of these lines with A B, draw straight lines to the top of the cone C C C; draw D *e* (*Fig.* 34) perpendicular to A B or D A, and equal to *d c*; draw parallel to D A *a* 1, *b* 2, *c e*. Make D 1 on D *d'* equal to D 1 on the line D *e*; also make D 2' equal to D 2, D *d'* equal to D *e*; then join the right lines 1 F, 2 F, and *d'* F. On the cutting

line D E, where it is intersected by the lines meeting in the top of the cone C, draw short perpendicular lines to D E, meeting the corresponding lines in the position 1′ F, 2′ F, and *d′* F; and their points of intersection with these lines will be points in the section of the cones through which to trace the curve E G *d′* (*Figs*. 35 and 36), and E G H (*Fig*. 34), which will produce one half of the conic section, and of course the other half will easily be obtained. All these sections being obtained on the same principle, renders any farther explanation unnecessary. *Fig*. 34 produces the ellipsis, 35 the parabola, 36 the hyperbola, &c. In *Fig*. 35, the cutting plane D F is parallel to the side A C (*Fig*. 36). It meets the opposite cone I C H in the point H, &c.

PROBLEM 19.—*To describe the section of a cylinder according to a given position of the cutting plane on the elevation.*

Let A B C D (*Plate* II. *Fig*. 37) be the elevation of a right cylinder, C D being the base F G, the given position of the cutting plane. On C D, describe a circle equal to the diameter of the cylinder. Divide this circle into any number of equal parts, as 1, 2; 3, 4, &c.; draw lines on these divisions, passing perpendicularly through C D till they reach F G; and on F G erect the corresponding perpendiculars to F G, 1, 2, 3, &c.; extend G F to H; make H *i* equal to the semidiameter of the cylinder; draw 1 *a*, 2 *b*, 3 *c*; make H *a′* equal to H *a*, H *b′* equal to H *b*, and so on, as in the last problem; then draw lines from these points (*a′ b′ d′*) parallel to H G F, and these lines will intersect the ordinates 1 *x*, 2 *x′*, 3 *x″*, &c. Lastly, through these intersections draw the curve, and the figure is completed as required, &c.

The following Problems will also be useful in laying off the Conic Sections, and a few other curves essentially necessary in ship-draughting.

PROBLEM 20.—*To lay off an oval, by measuring the ordinates with the compasses.*

Let A B C D (*Plate* II. *Fig*. 38) be the elevation of the cylinder, E F the cutting plane; divide the semicircumference of the cylinder into any number of equal parts, as 1, 2, 3, &c.; draw lines through these divisions parallel to the sides of the cylinder, extending down to the cutting plane E F, as *a* 1, *b* 2, *c* 3, &c.; then, at these intersections on E F, draw lines at right angles across it; from the diameter A B, measure on the parallel lines the distance to the circumference at each division; mark this from each side of the cutting plane, on its corresponding cross line, *a*, 1; *b*, 2, and so on; then through all these points, on the lines which cross the cutting plane, draw the curve, and the oval will be completed.

Fig. 39 exhibits another method of constructing an elliptical curve. Let A B be the height, and C D the breadth; describe the quadrant C E; divide D E into any number of equal parts, as 2, 4, 6, 8; from each of these divisions draw lines parallel to C D, and to meet the quadrant, as 7 *a*, 6 *b*, &c.; also divide the height D B into the same number of equal parts, as 8, marking their numbers on C A; also from these divisions draw lines across, parallel to C D; and from the point where the first-drawn lines intersect the circle, draw vertical lines parallel to D B or A C, as *a h*, *b i*,

$c\,j$, &c.; and where these intersect, their corresponding cross-lines will be points through which to draw the curve. By this method are the taper and swell of columns, and also the swell and taper of the masts and bowsprits of ships, set off.

PROBLEM 21.—*To construct or describe an ellipse of any given length and breadth.*

Let A B (*Plate* I. *Fig.* 22) be the given length, C D the breadth, the figure being bisected perpendicularly by the diameters A B and C D. Take the difference between A E and C E = A a, and from any point P, in the line E D, describe a small arc, cutting E B in Q; then, from the point P, through the intersection thus made, draw a straight line, as P Q R; make the distance P s, on the line P R, exactly equal to E B; and in like manner take any other point in C D, as p, and with the distance A a, as before, and centre p, describe another small arc, intersecting E B, through which, and point p, draw another right line; then again take the half-length of the oval in the compasses; set the one point on p, and it will cut the last-drawn line in s'; in like manner, continue to find a number of points, $s\,s'\,s''\,s'''$, through all which trace the curve, one quarter of which will thus be completed, and the others may be described in the same manner.

Method by continued motion with the trammel.—The trammel is an instrument (represented by *Fig* 23) made of wood, by joining two pieces together accurately (in the form of a cross) at right angles. Each piece has a groove cut in its upper side, in which grooves are fitted pieces of wood or iron, called sliders, as they slide backwards or forwards in the grooves. To these are fixed a pin, which projects upwards, and on these are fixed a ruler or straight edge $a'\,a''$. In describing an oval by this instrument, a pencil or point is fixed at a''; and supposing it to be so far completed, and the point drawn in the direction a'' B, the slider in the arm D moves towards the centre, while that in the arm C recedes from it, and moves towards B. The principle on which the trammel is constructed is the same with the last method of setting off the oval. The distance between the sliders, on which the ruler is placed, is always equal to the difference between half the length and half the breadth of the ellipse; and the distance between the slider next the tracing point and that point, is equal to half the breadth. This is the rule for setting this instrument to describe an oval of any given dimensions.

Another method.—Let A B (*Plate* I. *Fig.* 24) be the given length, D E the breadth, and C the centre, with the distance; A C in the compasses, and centres D and E; describe small arcs intersecting A B, the transverse in the two points f and f', which are two foci of the ellipse; assume any point, as a, in the transverse; extend the compasses from a to B; shift the point of the compasses from a to the focie f, and describe the small arcs on each side of the transverse at the end B, and marked $a'\,a''$ in the figure; then again take the small distance a A; from the transverse, set the point of the compasses in the other focie f', and describe a small arc, intersecting the former in the points $a'\,a''$; and by reversing the process, the other end A of the oval may be proceeded with in the same manner. This being done, assume another point b in the transverse; in like manner, take the distance b B, and with the centre f de-

scribe the arc b'; also take the distance A b in the compasses and centre f'; intersect it with another small arc, as before; and thus by assuming a number of points, c, d, e, f'', and proceeding with each in the above manner, a number of other points, c', d', e', f'', may be obtained, through which to trace the curve.

Another method, by continued motion.—Having found the two focies f, f', as before directed, stick a pin or needle in each; take a thread that will reach from one of the focie f to the vertex B; twist a pencil into the thread, as at G; move the pencil round, keeping the thread tight against the pins in the two focie, and thus the oval may be described. The thread may either be made to slide round the needles, or be tied to them, and the point allowed to slide against the thread.

Another method, by sweeps of the compasses.—Let A B (*Plate* I. *Fig.* 25) be the length, and D E the breadth of the figure. Make E G equal to the difference between half the length and half the breadth; bisect G B perpendicularly by the line $a\,b$; mark the point P, where the transverse diameter is intersected by this line, which assume for the focie; transfer the point P on the other half of the transverse C A; make C d equal to C b; draw the lines $d\,h$, $d\,i$, and $b\,j$; then with centre P, and radius P B, describe the end of the oval a B h and i A j with centre d and radius d D; describe the portion h D i; with centre d' and the same radii, describe the portion j E a. When the length of the oval does not exceed the breadth greatly, the change of the curvature at the joinings is but slightly marked; but when the length exceeds the breadth by one-third, a greater number of centres should be employed.

Another method, by the intersection of right lines.—Let C D (*Fig.* 26) be the semi-transverse diameter; D B the semi-conjugate. About these diameters, erect the rectangular figure A B C D; divide A C into any number of equal parts, also A B into the same, marking them from C to A, and from A to B; then draw straight lines to their corresponding numbers, as done in the figure, and they will be tangents to the curve. This method is applied in forming many very beautiful curves. *Plate* II. *Fig.* 27, shews its application in forming the sweep for the mouldings on a ship's stern.

PROBLEM 22.—*To describe the parabola.*

First method, by tangents to the curve.—Let A C (*Plate* II. *Fig.* 28) be the base, and E D the height. Produce E D to B, and make D B = D E; join A B and B C; divide A B into any even number of equal parts, marking them from A to B; also divide B C into the same number of parts, marking them from B to C; join 1-1, 2-2, 3-3, &c. These lines will be tangents to the curve, and the curve A D C, drawn to touch these tangents, is the parabola required.

Second method, by ordinates.—Let A C (*Fig.* 29) be the breadth, and E D the height; complete the rectangle A C F G, so that the side G F may pass through D; divide A E into any number of equal parts, also E C into the same number; next divide A G and C F into the same number of equal parts, marking them from A to 1-1, 2-3, &c. Draw straight lines from each of these divisions to the point D; from the divisions on the line A C draw up perpendiculars, and they will intersect their corresponding diagonal lines; then through all these intersections, draw the curve A D C, and it will be the parabola required.

Third method, by continued motion.—Take a ruler or straight edge A B C (*Plate* II. *Fig.* 30) equal in length to twice the base of the intended parabola; fasten the ruler to a board or on the table; take a common square, or two pieces of wood joined together at right angles, at a convenient distance and parallel to the straight edge A B C; draw a line D E for the base of the parabola; make F G perpendicular to D E, and equal to the intended height. Bisect F E in *h*, draw *h* G from the point *h;* make *hi* at at right angles to G *h;* produce G F to the point *i;* take the distance G *i* in the compasses, and with the points D and E as centres, describe arcs intersecting F G in P; then stick a pin in P, fasten the end of a thread to it, the other end at the point *r* in the square blade; then slide the stock of the square *x x′* from B towards A, keeping a pencil in the point S, which will slide down towards *r*, and thus trace the curve G S D, which will be one half of the parabola, and turning the square over to the other side of the line F G, the parabolic curve may be completed. The length of the thread P S *r* is equal to G *i*.

Another method, by finding points in the curve, on the same principle as the last.—Let V P (*Plate* II. *Fig.* 31) be an absciss, P Q its given ordinate. Bisect P Q in A, and construct A B as before; transfer P B to V F and V C, so shall C be the focie; draw double ordinates S S′, S″ S‴, &c. perpendicular to V P; then with the radius F R and centre C, describe arcs intersecting the ordinate R in the points S S′; take the distance from F to the next ordinate below C, and with centre C as before, describe arches intersecting in S″ S‴, and so on with all the ordinates; then through all these spots S S S S S, draw the parabola as required.

Schol.—Ellipses and the opposite hyperbolas have each two vertices, but the parabola has only one.

PROBLEM 23.—*To construct the hyperbola.*

In this (*Plate* II. *Fig.* 32) the degree of curvature is not fixed by the height and width of the arc, but is capable of every degree of variation between the curvature of the parabola and the straight lines of a triangle; the variation depends on the position of the point B, for the nearer this point is to D, the nearer the figure will be to a triangle, and the more distant it is, the nearer will the figure be to the parabola. To draw the curve, divide A F and A E each into the same number of equal parts; and from the division 1, 2, 3; on A F, draw right lines to D; also from the division or leg on A E, draw lines to the point B, and where these intersect their corresponding lines draw a curve, and it will be the hyperbola required.

Another method.—Let A (*Plate* II. *Fig.* 33) be the centre of the hyperbola, C B the transverse; erect C G perpendicular to C B, and equal to half the conjugate; then on A as a centre, and radius A G, describe a semicircle meeting C B, produced in H and *h*, which will be the two focie of the hyperbola; then assume a number of points in the transverse, as *i′ j′ k′ l′ m′* &c.; with the radius B *i′*, B *j′*, B *k′*, and centre *h*, describe the arcs N, N, N, &c. and with the radius C *i*, C *j*, C *k*, &c. respectively, and centre H, describe arcs cutting the former in N, N, N, &c.; then through all these intersections draw the curve, and it will be the hyperbola required.

PROBLEM 24.—*To construct the conchoid.*

The Conchoid is the name given to a particular curve, by its inventor Nichomedes.

Let A B and P Q (*Plate* II. *Fig*. 40) be two lines intersecting each other at right angles; from the point P draw a number of lines P *s*, P *s*, &c.; G is the centre, and P is called the pole of the conchoid; on thelines drawn from the pole, take always the distances E *s*, E *s* = G D, and through all these points draw the curve S S D S, &c. and it will be a conchoid; also take the distance G D′, and apply it also on each of the radiating lines from A B, and through these spots draw the curve S′ S′ D′ S′, and it will be what is called the second conchoid.

PROBLEM 25.—*To construct the cessoid, or cyssoid.*

This curve was invented by an ancient Greek geometrician, for the purpose of finding a mean proportional between two given lines. It is constructed thus: Draw any straight line A B C (*Plate* II. *Fig*. 41), on which erect the perpendicular B D; bisect it in E, with E as a centre, and radius E B; describe a semicircle; form the point D, draw a number of straight lines to meet the line A B C, as D F, D F′ D F″, &c.; take the distance from D to where the circle is cut by the line D F; set this on the same line D F from the horizontal line A B C; and in like manner take always the distance from D to where the circle cuts the lines D F, and setting these distances from the line B C on their respective lines D F′, you will obtain a number of spots *r*, *x*, &c. through which the curve is to be drawn. This method is suitable for projecting and setting off the curve of the riband lines in the floor plane, in drawing the plans of vessels.

PROBLEM 26.—*To construct cycloids, &c.*

The Cycloid or Trochoid is the curve described by any part of the circumference of a circle when rolled along a plane. This is an elegant mechanical curve, and has been very frequently used by geometricians and mechanics. It was first noticed by Descartes. It is also the curve of quickest descent. It is commonly constructed by continued motion, thus:—Let a ruler A B (*Plate* II. *Fig*. 42) be laid flat on the paper on which the cycloid is to be drawn, take a small wheel equal in diameter to the axis of the cycloid D G, that is, its greatest deflection from the straight line; fix a pin or pencil in any part of the wheel or generating circle, as at P; bring this to the starting point of the ruler A; then roll the wheel towards B, observing that it does not slip on the ruler; and when the point has arrived at B, it will have traced the cycloid as required.

If P be a point without the circle, as in *Fig*. 43, and the circle be made to roll along as before, the curve E P V P′, described by the point, will be what is called the Curtate Cycloid.

But if the point be any where within the circumference of the generating circle, as in *Fig*. 44, the curve described by that point is called the Inflected or Prolate Cycloid.

Construction by finding points in the curve.—Draw A B equal in length to the intended cycloid; divide it into 22 parts; take 7 for the diameter of the generating circle; at the point A, *Fig*. 45, erect a perpendicular, on which describe the circle; divide its cir-

cumference into 8 equal parts by the diameters 1, 2; 3, 4; divide the distance from A to the vertex into 4 equal parts, at each of these draw up perpendiculars to A B, as 1 E, on each of which describe circles of equal *radii* to the generating circle; now observe that the diameter of the first drawn circle 1 5 will, after it has rolled along A B to the first division from A, stand in the vertical position 1 E, and the point 8 at A will have risen to 9. In like manner may the point be traced through all the other circles at each division of the line A B, and the figure completed. We have only drawn the one half of it on the plate. The curve for the curtate and prolate cycloids may be traced in the same manner.

PROBLEM 27.—*To set off a very flat sweep from a circle.*

Let A B (*Plate* II. *Fig.* 46) be the given length of the chord, C D its versed sine; then on the centre C, with radius C D, describe the semicircle *a* D *e*, or the quadrant D *e* will be sufficient; divide the radius C *e* into any number of equal parts; also divide the quadrant D *e* into the same number of parts; next divide C A and C B each into the same number of equal parts; and at this last division draw up lines perpendicular to A B; draw lines from each of the divisions on the radius C *e* to the corresponding divisions on the quadrant D *e*; next take the distance 1 1′, 2 2′, 3 3′, 4 4′, from the quadrant, and transfer these to their respective lines on A B, as 1 1″, 2 2″, 3 3″, &c.; then bend a *batton* round to all these spots, and draw the curve as required.

By this method the curve and taper of some of the principal spars of a vessel are set off, such as the yards. Of course, the curve is much flatter than represented in the figure. In lining out a yard, C D is made equal to half the diameter at the slings or middle of the yard, and the distance 4 4′ equal to half the diameter at the end. This method of setting off a fair curve, when the radius is two great to allow of its being trained from a centre, which frequently occurs in shipbuilding, is expeditiously performed by the workman; and sometimes the following method is used for the same purpose:—Let A B (*Plate* III. *Fig.* 47) be the chord C D, the rise of the curve C D being drawn perpendicular to A B; draw the straight lines A D and B D; from D draw D E and D E′, so that the angles A D E and B D E′ shall be respectively equal to the angles A D C and B D C; divide the rise into any convenient number of equal parts, as 1 2 3 4, with the same distance in the compasses; turn them over on the lines D E and D E′; from the points A and B, draw straight lines passing through the divisions 1, 2, 3, on the line D C; also draw the dotted lines from the points A and B, to the divisions 1, 2, 3, on the lines D E and D E′, and these last-drawn lines will intersect the others in the points *a a′ a″*, *c c′ c″*, and as these points will fall into the curve; then take a batton, and bend round to all these spots, and draw the curve as required. If A F be made parallel to E D, it will intersect the line H D C continued inwards in the centre of the circle. In practical application of this method, where the rise D C is very small in proportion to the length of the chord, the lines D E and D E′ may be omitted, and the divisions marked on D H, which will shorten the process a little, while at the same time the curve will be sufficiently near to the circle for many purposes. To the methods already given for setting off a fair curve, such as the por-

tion of a circle, we have to add another, which will be found convenient for setting off a very flat circular curve, such as the sheer of a vessel's upper works, or the like. By the sheer is meant the curving upwards of the two ends of a vessel above water.

Problem 28.—*To set off a flat curve from a straight line, or the sheer of a vessel from a straight line on the side.*

Supposing you make a straight line along the ship's side from stem to stern, at the height of the lowest part of the intended sheer, which is the point of contact; divide the distance between this spot and the extreme end or stem, into any number of equal parts, making them 4, 6, 8, 10, or 12 feet apart, as the length of the vessel and convenience for the off-sets may require, and an equal number of divisions will be found to answer best, such as 4, 8, or 16, as these may be reduced to their lowest terms by halving, quartering, &c.; in like manner, divide the distance from the point of contact of the tangent line to the stern,—then we say, that the rising of the curve above the straight or tangent line at each division, will be as the square of the distance from the point of contact.

For example:—Suppose a vessel of 90 feet long, and the lowest part of the intended sheer-line to be 48 feet from the stem; let this distance be divided into 8 equal parts, making 6 feet between each. Again, suppose the distance from the point of contact to the stern 42 feet $=7$ divisions of 6 feet each; let the greatest rise of the curve from the tangent line at the stem or 8th division be 32 inches. Then to find the height of the rise at the first division from the point of contact, divide the height by the square of the 8th division; but as 32 cannot be divided by 64, the square of 8, the 32 may be reduced into half-inches, quarter, or 8th parts of an inch, and $32\times8=256$ eight parts, which, divided by $64=\frac{256}{4}=4$, which is $\frac{4}{8}$, or one half inch for the rise of the curve at the first division from the point of contact.

Then the rise of the first division being $\frac{1}{2}$ inch, the rise of the second will be 4 half-inches; rise at the third division 9 half-inches; at the fourth 16 half-inches; and so on, the rising at each division always increasing as the squares of the divisions.

Again, suppose the greatest rise to be only 24 inches instead of 32, and the divisions as before; then $8\times8=64$, and $24\times8\div64=\frac{3}{8}$ of an inch for the first rise. If the greatest rising be 16 inches, and the divisions as before, then $16\times8=128$, which divided by 64, gives $\frac{1}{4}$ of an inch for the rise at the first division; and if the main rise is 8 inches, gives 1-8th part for the first rise, which in every case is the quotient of the main height divided by the square of the divisions.

Supposing the greatest rising to be 36, 27, or such a number, which will not divide equally, the following method of marking the rises on a batton will answer the same purpose:—After having made the divisions on the side as before, take a batton and measure the greatest rise on it; divide this distance into 4 equal parts, the first of which from the bottom, will be the rise of the middle division from the point of contact; and if the distance from this point to the bow is divided into 8 equal parts, the 4th part of the rise at the middle division will be the rise at the second division, and the 4th part of the rise of the second division is the rise of the first.

Again, if the length from the point of contact is divided into 16 équal parts, the 4th part of the main or greatest rising of the curve from the tangent is the rise at the middle or 8th division; also the 4th part of that height is the rise at the 4th division. Thus, the 4th part of the height at any place is the height of the curve above the tangent in the middle, between that place and the point of contact; 1-16th part of the rise at the 4th division is the rise at the first, and also 1-4th of the rise of the 2d division is the rise of the first. Now from this it follows, that if we divide the rise of the curve from the straight line at the 4th division into 16 equal parts, we shall have a scale formed from which we may place all the other risings on the batton, and as they increase as the squares, they will stand thus, 1, 4, 9, 16, 25, 36, &c., 36 being the rise at the 6th division.

The increasing risings at each off-set being as the numbers 1, 3, 5, 7, 9, 11. The height of the 4th division being divided into 16 equal parts—1 is the first rise, 4 the second, 9 the third, 16 the fourth, and so on; of course, in marking the batton, we have only to add the rising numbers to the last heights always. Thus, at the 3d division, the height of the curve from the straight line is 9, and it is required to determine the height at the 4th division; now the increasing risings at each off-set are as the numbers 1, 3, 5, 9, &c., and as the 1 stands at the point of contact where there is no rising, the number 7 stands at the third, and $9+7=16=$ the rise at the fourth division from the point of contact; and 16 is the square of the fourth division, the rising being always as the squares of their distances—

$$\text{Expressed thus,}\begin{cases} 0,\ 1,\ 4,\ 9,\ 16,\ 25, & \text{the height of the curve.} \\ 1,\ 3,\ 5,\ 7,\ \ 9,\ 11, & \text{the increasing numbers.} \\ 0,\ 1,\ 2,\ 3,\ \ 4,\ \ 5, & \text{divisions from the point of contact.} \end{cases}$$

Figure 49, and A Plate III. represents the curve laid off, and the batton with the risings marked on it; which may be marked in a few minutes to the greatest degree of nicety by attending to the above explanation; also by inverting the batton (turning it end for end) the same division will set off the points through which the curve is to pass from the chord (*See fig.* 49), as an inspection of the figure referred to will render obvious.

Scholium.—We have here to observe, that the above method will only produce part of a fair circle, while the height of the greatest rise is less than 1-4th of the length of the semi-chord, or while the arch is less than 1-8th part of the whole circle; for when the rise becomes greater than 1-4th of the semi-chord, or the arc more than 1-8th of the circle, the curve so traced by this method becomes sensibly elliptical. However, in setting off the sheer of a vessel as now described, the curve will be as near the true circle as is necessary, because the greatest rise will not require more than the 20th part of the length of the ship.

PROBLEM 29.—*To find the radius of a given arc.*

Let A D B (*Plate* III. *Fig.* 48) be the given portion of a circle; draw the chord A B, bisect it in C; draw D C O F perpendicular to A B; draw B D; then draw a line B E, making the angle C B E equal to the angle C D B, or D B E a right angle,

then will the line B E cut D C F in F; bisect D F in O, then will O F or O D be the radius required. The angles B C D, C D B, and D B C of the small triangle, are each respectively equal to the angles F C B, C B F, and B F C of the larger triangle; consequently the leg C D of the small triangle bears the same proportion to any of its other sides as C B, that the side C B of the larger bears to any of its sides.

Example—Let the length of the chord A B=20 feet.
Rise of the curve - C D= 4 do.
Then to find the radius of the sweep—
As D C : C B : : C B : C E and C F+C D=D F, then
$\frac{DF}{2}$ = the radius as required,—4 : 20 : : 20 : 100 = C F
and $\frac{100+4}{2}=52$ feet, the length of the radius.

PROBLEM 30.—*To set off a very flat elliptical curve.*

Let A B (*Plate* III. *Fig.* 50) be the length, and C D the greatest rise of the curve; with centre C and radius D, describe the quadrant D e; divide C e into any number of equal parts, as 1, 2, 3, &c.; at these divisions square up lines perpendicular to A B; next divide C B and C A into the same number of equal parts; number them from A and B, as 1, 2, 3, &c.; at these divisions draw lines vertical to A B; then take the height from the centre-line A B to where the first division line of the diameter of the circle cuts its circumference; place that height on the first division from A and B respectively; in like manner take the height 2, 2′; place it on the second division from A and B, or you may draw lines from where the vertical lines cut the circumference of the circle, parallel to A B, and they will cut their respective lines in points through which the curve is to be drawn, as an inspection of the figure referred to will clearly illustrate.

Scholium,—This problem is resolved in a preceding one, (*Prob.* 20, *se ond method*, *Fig.* 39, *Plate* II.) and is here given as it is applied in lining masts and spars: Thus, suppose A B to be the centre-line of a mast whose length is a b; suppose the greatest diameter to be about C, you make C D the semi-diameter, a the semi-diameter at the foot, and b the semi-diameter of the head; describe the quadrant of a circle as before with radius C D; then take the semi-diameter of the head in the compasses; hold the one point somewhere on the line C e, and vertically up from the same till it cut the circumference of the circle in the point 1′; then join these two points 1, 1′; divide C 1 into any number of equal parts, also C b into the same number of equal parts, and drawing up perpendiculars at all these spots, measure the rounding of the mast at each from the quadrant of the circle, and you have the semi-diameter of the mast at the different off-sets, from the middle or greatest diameter, upwards; and the same being done for the under half, you have the proper sweep to line the mast from the heel to the top.

PROBLEM 31.—*To set off an essing curve from a circle.*

Draw a straight line A B (*Plate* III. *Fig.* 51); make B C perpendicular to A B, and equal to the given breadth of the curve or water-line; bisect it in O; describe the semicircle C D B; divide it into any number of equal parts; take any distance in the compasses according as the curve is to be quirked or finely tapered; turn them over on the line A B the same number of times as the semicircle C D B is divided; or when the length of the tangent to the curve is given, divide it into the same number of equal parts, and at each of these, square up lines perpendicular to A B; then draw lines from all the divisions on the semicircle parallel to A B, and they will each cut their respective vertical lines 1, 2, 3, 4, &c. extended on the line A B; through these intersections the essing curve is to be drawn as represented in the figure.

CHAPTER II.

MECHANICS.

MECHANICS form an important part of Natural Philosophy. It is divided into two parts, the theoretical and practical.

The Theory of Mechanics is derived from the laws or principles of Dynamics. It considers the nature of powers or moving forces, their properties and motions, and the action of one body upon another, not as tending to change the constitution, but the position of the body.

The practical part comprehends the construction of machinery of every description.

Under the term Practical Mechanics, I shall explain the principles of what are generally considered the mechanical powers, viz. the Lever, the Wheel and Axle, the Pulley, the Inclined Plane, the Screw, and the Wedge—the three last of which, however, are founded on the same general principles.

It is evident, that if there be one class of mechanics more indebted to a knowledge of these powers than another, it is the shipwright. From the time the keel is laid down, till the vessel is launched into her destined element, he is continually assisted by these powers, in the various combinations in which they are capable of being united; and the mariner derives no less advantage from a knowledge of the principles of mechanics, in hoisting and setting his sails to the best advantage. The knowledge which these possess of the mechanical powers, and the principles which govern them, is acquired by experience in using them; and it appears like an instinct. Until the young shipwright or seaman has acquired this knowledge, his exertions are feeble, and he is often surprised at the advantage which his more experienced mates possess over him in this respect, and it is equally necessary to have an understanding of these principles, before attempting a consideration of the science of Marine Architecture, for without this, we cannot conceive the effect of any proposed change in the construction or proportion of any of the various parts of the hull or outfit of a vessel.

Definitions.

Before proceeding to consider the principles of the mechanical powers, I shall define a few of the most common terms employed; as, space, body, force or power, weight or resistance, motion, direction of motion, quantity of motion, centre of motion, velocity, inertia, gravity, centre of gravity, equilibrium, friction, action of body, cohesion, momentum, &c.

Space, in the most extended sense, means unlimited extension, if we can so conceive it. It is immoveable, but penetrable by matter. This is called absolute space, as it cannot be measured; but a portion of it may be measured, which is called relative space, as it is that variable portion of absolute space which our senses define when we compare it with bodies within it.

Body is any quantity of matter or substance obvious to some of the senses, extended in three dimensions, susceptible of motion, extension, and impenetrability. By this last is meant, that no two particles of matter can at the same time occupy the same identical portion of space. A body which gives way to another, but afterwards resumes its former shape, is called an elastic body. Those which remain under the change produced upon them are called non-elastic bodies. Both hard and soft bodies possess these properties. Density is a property of body, denoting the vicinity or closeness of the particles of which it is composed. It is used as a term for expressing the proportion of the number of equal particles in all bodies.

Force, or *Power*, generally denotes whatever acts on a body, so as to move it from one place to another, or whatever causes a change in the state of a body, whether that be motion or rest. If motion be produced suddenly by any moving power, it is called impulse. That which impels a body with increasing velocity is termed accelerative force; and if it move the body with equally increasing motion, the moving power is called uniform accelerative force.

Weight, or *Resistance*, is a measure of gravity. Power and weight are generally used as opposite forces. Power is the agent that acts, and weight is the body acted upon; and as it opposes or resists the power from moving the body, it is called the resistance; and when the power exceeds the weight, the resistance is overcome.

Motion is a continual change of place. Its uniformity is known by its passing over a given space or spaces in given times with equal velocity.

Direction of Motion is the course or line which a body describes in moving from one place to another.

Quantity of Motion is the proportional velocity which a body bears to its magnitude.

Centre of Motion is a straight line drawn, or supposed to be drawn, through the centre of a body, around which it moves or revolves. This line is also termed the axis of motion.

Velocity is the quantity of motion with which a body passes over a given space in a given time.

Inertia is the tendency of every body to remain at rest, or to continue in motion, by which it resists all attempts to change its place or line of motion. This is considered only an essential property of body, but not to constitute a force.

Gravity is that force or attraction by which all bodies are drawn towards the centre of the earth; and the degree of attraction on a body is called its weight. The force of gravity acts equally at all times on all bodies at the same distance from the centre of the earth, and nearly the same at any part of the earth's surface, but with somewhat less force towards the poles. All bodies which descend by this force are equally swift in their descent, if all resistance be removed.

Gravity acts on the particles of all bodies alike, and hence those bodies which consist of the greatest number of particles condensed into the same space, are the heaviest. Gravity and weight are nearly synonymous terms for attraction; but it is generally called gravity in the large body, and weight in the small. Thus, when we throw a stone, we conclude that the gravity of the earth will draw it down, or that the weight of the stone will cause it to fall to the ground. Gravity is divided into absolute and relative: the first is the tendency or degree of attraction with which a body descends towards the earth in free space; the relative is the degree of attraction with which it descends when immersed in a fluid, such as air or water.

Bodies near the surface of the earth are observed to fall through a space equal to about 16 feet 1 inch in the first second, at the end of which time the body gains a velocity which would carry it through double that space in the same time, that is, 32 feet. The velocity acquired in falling in any number of seconds, is the number multiplied by 32. The space which is fallen through in any time, is equal to the space described in the first second (16 feet) multiplied into the square of the given time. Thus the space passed through in two seconds, is $2^2=4\times16=64$ feet; for observe, that if it falls through 16 feet the first second, and gains a velocity of 32 at the end of that second, then at the end of the next it will have fallen $16+32=48+$ what it fell the first second, which is 16, and $48+16=64$. The number of seconds a body requires to fall through a given space, is equal to the fourth part of the square root of the height. Thus suppose a body to fall through 64 feet,—required the time? Then the square root of $64=8$, and $\frac{1}{4}$ of $8=2$ seconds, the time. The velocity acquired in falling from any height is equal to eight times the square root of the height. Thus, if it fall through a space of $3^2=9\times16=144$ feet at the end of the third second, it will have a velocity of eight times the square root of that height, which is 12, and $12\times8=96=$ the velocity at the end of the third second; and the body, with its acquired velocity in any time, will fall through double the space in the same time, supposing the gravitating force to cease at the end of the first second.

Centre of gravity.—The centre of gravity is that point in a body from which, if it were freely suspended, it would remain at rest in any position in which it might be placed.

All tangible bodies may be supposed to have a centre of gravity; and when any number of bodies are joined together, they will have one common centre of gravity.

When the centre of gravity of any body, or system of bodies combined, is sustained,

the body is also sustained; but the body is not sustained unless its centre of gravity be sustained, that is to say,—the body will be in motion until its centre of gravity is supported, and brought to a state of rest.

The body A (*Plate* III. *Fig.* 53) will evidently fall off the plane A B, because its centre of gravity is not sustained; the body D also will not remain in the position represented, because its centre of gravity is not supported, the straight or vertical line which passes through this centre falling without the base. If a body is balanced on a pivot below the centre of gravity, it will not remain at rest until it has brought the centre of gravity below the points of suspension.

The centre of gravity of any body is easily found, by dividing the sum of the momenta of its different parts from any plane by the sum of the different parts, and it may be taken either in surface or weights.

Thus, suppose it is required to find the centre of gravity of a rectangular surface, 8 feet in length and 4 in breadth.

1*st*, In respect of the length from one end :—

There are 32 square feet of surface, the first foot from one end containing 4 feet in breadth; the second, 4 feet of breadth, and so on to the 8th.

The distance of the centre of gravity of the first 4 feet of breadth from the end, is 6 inches; of the second 4 feet of breadth, 1 foot 6 inches; of the third, 2 feet 6 inches, and so on, increasing by one foot; at last making the centre of gravity of the eighth division, or 4 feet of breadth, 7 feet 6 inches from the end. Then, for the momenta, multiply the surfaces by the distance of their centres of gravity from the end; thus—

$$\left.\begin{aligned} 4 \times .5 &= 2 \\ 4 \times 1.5 &= 6 \\ 4 \times 2.5 &= 10 \\ 4 \times 3.5 &= 14 \\ 4 \times 4.5 &= 18 \\ 4 \times 5.5 &= 22 \\ 4 \times 6.5 &= 26 \\ 4 \times 7.5 &= 30 \end{aligned}\right\}$$

Then 32) 128 (4 feet, the distance of the centre of gravity from the end.
128

Surface 32 128 Momenta.

2*d*, For the position of the centre of gravity, in regard to the breadth :—

In this position, each foot from the edge or side contains a surface of 8, and $8 \times 4 = 32$.

Then the distance of the centre of gravity of the first 8 feet of surface from the side is 6 inches; of the second, 1 foot 6 inches; of the third, 2 feet 6 inches; of the fourth, 3 feet 6 inches;

$$\begin{aligned} \text{And } 8 \times .5 &= 4 \\ 8 \times 1.5 &= 12 \\ 8 \times 2.5 &= 20 \\ 8 \times 3.5 &= 28 \end{aligned}$$

32 64

And 64 divided by 32, gives 2 feet for the distance of the centre of gravity from the side.

Consequently the centre of gravity of a square or rectangular surface is in the intersection of two straight lines drawn perpendicular to each other—one through the middle

of the length, and the other through the middle of the breadth of the surface; or in the intersection of two straight lines drawn from the opposite corners of the figure. If the body be considered a solid, its centre of gravity must be determined in respect to a third plane, in the same manner as we have proceeded with the other two.

I have chosen to illustrate the rule by a simple example, that our young readers may draw out the figure for themselves in considering the question.

In like manner may the centre of gravity of all sorts of regular or irregular bodies be determined, viz. by dividing them into a number of parts, multiplying each by the distance of its centre of gravity from one end, then dividing their sum by the sum of all the parts as above; for this purpose the surface of the body may be divided into a number of squares or triangles, the centre of gravity of which is easily known. Thus, the centre of gravity of triangular bodies is situated at one-third of a straight line drawn from the middle of the base, or any of the sides, to the opposite angular point.

The centre of gravity of a parabola is at the distance of 3-5ths of the axis from the vertex; that of a cone at 3-4ths of the length of the axis from the apex; and that of a hemisphere at 5-8ths of the radius from the vertex. I shall hereafter shew some geometrical methods of finding the centre of gravity, when we come to consider the side-pressure of the sails of vessels.

Equilibrium.—An equilibrium takes place, when bodies that are freely suspended and acting in opposition to each other, balance one another in every position, when they remain at rest, or when the generating forces are equal.

Friction is the resistance which one body makes to another acting upon it, and which prevents the bodies from sliding easily upon each other. It is the second impediment to motion, and can scarcely be employed to generate it. It is therefore unlike gravity and other forces, which, if they retard motion in *one* direction, always accelerate it in *another*. The force of friction is the greater, the greater the roughness of the surfaces moving on each other, and also the greater the force with which they are pressed together; but the retardation which it opposes to motion is said to be the same for all velocities, which is not correct in all cases. It is also sometimes affirmed, that the ratio of friction to the pressure is the same, whatever be the extent of the surfaces which rub on each other, which is irreconcileable with experience, however reasonable in theory. The surface of any body cannot be made perfectly smooth, and hence friction arises from the protuberances on the surface of the one falling into the cavities of the other—as the body A (*Plate* III. *Fig*. 52) is prevented from sliding down on body B by the roughness of the plane of contact C D. Bodies which appear quite smooth to the naked eye, have a very contrary appearance when viewed through powerful magnifying glasses; nevertheless, the friction of some bodies is not diminished in proportion as the polish of their surfaces is increased, which may arise from the bodies being held more firmly together by a mutual attraction. The subject of friction has been treated by philosophers with minute attention, and as a knowledge of the results of some experiments may be very useful to practical mechanics, the following particulars on the friction of solids, from Professor Leslie's Elements of Natural Philosophy, are inserted:—

"*Friction on a plane moving in a fluid.*

"Nautical miles per hour,	1,	2,	3,	4,	5,	6,	7,	8.
"Motive powers in lbs., or Friction on one square foot of surface,	0.013,	0.045,	0.087,	0.148,	0.237,	0.294,	0.327,	0.466.

"At eight miles per hour, the friction on one square foot of surface does not amount to half a lb.

"*Friction of solids on each other.*

"Assuming the pressure equal to 100 parts the friction of oak against fir, is 66 in the direction of the fibres, but amounted only to 16 when moved with the velocity of a foot each second. The friction of oak against oak in the direction of the fibres is 45, and across them only 27, the effect being farther reduced to 10 by motion. The friction of fir against fir in the direction of the fibres was 56, which sunk to 17 during motion. Elm against elm, in the direction of the fibres, 46, which motion reduced to 10. The friction of copper against oak was lengthways 18, and only 8 when kept in motion. The friction of iron upon oak 28, which diminished to 11 when kept in motion. The mutual friction of metals appeared in general to be less affected by motion, as iron had its friction diminished in passing from rest to motion only from 28 to 25. The friction of brass upon iron was diminished by motion from 25 to 17.

"The application of grease, soap, or other soft liniments, to the rubbing surfaces, generally diminishes the friction, though in very different degrees. Oak upon oak, fresh greased, has its friction diminished from 45 to 43, and reduced to 26 after the tallow had been thoroughly imbibed into the wood, and left a glossy smoothness. The greasing of the surfaces of copper and iron lessens their friction to 10.

"A piece of greased oak, the moment it is laid upon another, is drawn with a force of 4, but would have the friction augmented in three seconds to 10, in one minute to 16, and in two hours to 28, and in the space of five or six days to 44. The friction of wood against iron increases likewise during a sensible time. An iron axle turning in a brass socket has its friction reduced from 26 to 16, or lessened by more than one-third part; when fresh greased, the friction between the axle and the socket is 9. The friction of oak upon oak (with tallow between at the instant of contact) is only 1-12th part of the whole pressure, but becomes one half more in the space of a single minute, and is tripled in 24 hours—equal to about 1-4th part of the incumbent load.

"The diminished obstruction resulting from a swift congress is visible in the mutual attraction of wood; it is still more prominent in the heterogeneous contact of metal and wood, and is most remarkable when a coat of tallow has been interposed. A ship," observes the Professor, "is launched along sliders commonly sloping from 4 to 5½ degrees; the lowest friction is here exerted, all previous adhesion being destroyed by the blows of the mallet, and shocks given in displacing the wedges; the momentary friction being 4, leaves an accelerating force of 3, which hurries the vessel forward notwithstanding its immense pressure of perhaps 3.5 tons on every square foot of surface of the slide. If any imperfection in the *tract* should arrest the ship's progress, it will soon gain such

adhesive power as to render its removal extremely difficult, and a tremulous motion is the only expedient to urge forward the ponderous mass."

The above observations are very judicious, and as a knowledge of the friction of different materials must be useful to the shipwright, who must depend in a great measure upon this phenomenon for the durability of his work, I have been induced to make the above extract.

When the different pieces of which a ship is composed are closely fitted together, it is certain that the cohesive friction tends greatly to prevent them from slipping or moving in the direction of their joining planes, by which the treenails, or bolts which fasten them, become doubly effective—*first*, while the surfaces of the two joining pieces adhere closely together, the leverage power of bending or twisting the bolts by which they are fastened is greatly diminished; and *secondly*, by the friction of the surfaces, when closely united, having a tendency to remain in their positions independent of any other additional fastenings.

Action of Body.—Stress or strain is the action of one body upon another to break or displace it. It is the cause of motion; the laws of which constitute one of the principal objects of Natural Philosophy. The branch of science which considers motion in its purest sense is called Dynamics, the principles of which, modified so as to apply to actual bodies connected and acting upon each other, so that they are not left to obey in a direct manner those impulses that may be given them, constitute Mechanics, to which belong the construction of all sorts of engines or machines.

Cohesion is the natural force with which the parts of all bodies resist every attempt to separate them; *Adhesion* is a modification of cohesion, relating to the force which connects the particles of liquids together.

Momentum.—By momentum is meant, the weight or mass of a moving body, multiplied into its velocity. Thus, if a body weigh 3 lbs., and be driven with a velocity of 6 miles per hour, its momentum is $3 \times 6 = 18$, which is the effect of that body at the given velocity. If a body weigh 9 lbs., and move with a velocity of 2 miles per hour, its effect will be equal $9 \times 2 = 18$; consequently, if these two bodies move in opposite directions and meet, then all motion in both bodies will be destroyed. In like manner, if two bodies are suspended from an axle or axles, and act in opposition to each other; and if the machine be so contrived that the two weights balance each other, and equilibrium exist; then if the axle be turned round, it will follow that the perpendicular ascent of the one, multiplied into its actual weight, will be equal to the perpendicular descent of the other, multiplied into its weight; the momenta of the two bodies are then said to be equal—for as they are both at rest or in motion at the same time, their ascents and descents will be made in the same time, and their velocities will be as the space passed through, that is, inversely as their weights. In this state of equilibrium the excess of weight in the one body will be counteracted by an excess of velocity in the other. Now, observe that the excess of the velocity of the power, which is always supposed the least of the weights, over that of the weight or resistance, is the measure of the power of the machine. If the power does not move faster than the resistance, the machine assists us no farther than changing the direc-

tion of the motion. This will become more evident after considering the mechanical powers.

After these definitions of terms generally employed in mechanics, we are now in some measure prepared to proceed in considering the mechanical powers, for a mathematical consideration of which, however, the following postulate is commonly given.

Postulate.—That a small portion of the earth's surface may be considered a plane: That the weight of a falling body does not affect the time of its descent: That bodies descend in lines parallel to each other, at least that there is no sensible deviation from their parallelism on such lengths of fall as we can effect: That a given weight acts with the same force at all times in all places, and also in all situations of its point of contact or pressure: That all planes are perfectly smooth, and even all bodies equally so: All right lines straight, inflexible, and without weight; all chords pliable and without friction: That all bodies are equally attracted by gravitation, whether they are near or distant from the ground.

It will appear from the above, that we propose to reason on the effect of perfect instruments, which, however, cannot be produced. It is therefore necessary in practice to make an allowance for friction, and the imperfect nature of machines, equal to the excess of the estimated effect over that found in practice.

There is one unalterable law to be observed in mechanics, viz. *What is gained in power is lost in time.* This implies, that if any machine be so constructed as to raise a given weight a certain height in a given time by the force of one man, one horse, or any other single force, no machine whatever can be made to enable the same force to raise double the weight to the same height in the same time, by the single power of one man or one horse—for if it be so contrived that one man can raise double the weight to the same height, he will take double the time to perform it.

Explanation of the Mechanical Powers.

A Mechanical Power may be defined to be the means by which the effect of a given force is increased, while the force itself remains the same. In the beginning of this chapter, we mentioned six of these powers. Some writers are pleased to consider the inclined plane, the screw, and the wedge, as one power, as indeed they are only different modifications of it. Some add what is called the Funicular machine as the seventh, and to this with equal propriety may be added the hydraulic, or Bramah's press, as the eighth mechanical power.

Of the Lever.—The lever is an inflexible rod of wood or iron, moveable about a centre, having a resistance at one end, and a force applied at the other. In a mathematical sense, a lever is an inflexible right line without weight. The point of support on which a lever turns, is called the fulcrum or prop; on this point all the parts of the lever turn as their common centre of motion, and their velocities are all respectively equal to their distances from this point. The power and weight are inversely as their distances from the fulcrum. When the resistance is to its distance from the prop, as the power is to its distance from the same, an equilibrium takes place; that is, when their momenta

are equal, the velocity of the power and weight are as their distance from the centre, hence their momenta are obtained. (See *Plate* III. *Fig.* 54.) Let W be a weight of 8 lbs. suspended 1 foot from the fulcrum F; P a power of 2 lbs. suspended from the long arm of the lever, which has a power of 4 to 1, the lever being five feet long, and resting upon the prop one foot from the end; then it is evident that the weight or resistance is to its distance from the prop, as the power is to its distance from the same, and consequently that their momenta are equal; $8 \times 1 = 8$, and $2 \times 4 = 8$; therefore an equilibrium has taken place, and the least additional force applied at P will raise the weight W. But observe, that the power P will descend 4 feet, while the weight is raised one foot. The velocity of the power to the weight is as 4 to 1. This kind of lever is called a *lever of the first order*, and in it, observe that the fulcrum F is between the power and the weight.

Of the second kind of Lever.—A lever is said to be of the second order, when the the weight or resistance is placed between the fulcrum or prop and the power. In this, as in the former, the advantage gained is as the distance of the power from the prop to the distance of the weight from the same, and the velocity of the power to the weight is in the same proportion. Again, I may mention that levers of all kinds are in equilibrio, when the intensity of the power, multiplied into its distance from the centre, is equal to the intensity of the weight multiplied into its distance from the same, *i. e.* when their momenta are equal. Thus, let A B (*Plate* III. *Fig.* 55), be a lever of the second kind, equal to 7 feet; let F be the fulcrum, at 2 feet from which, let W, a weight of 7lbs. be suspended—required, the power, pulling in the direction B C, to sustain the lever? Then $7 \times 2 = 14$, and as the momenta must be equal, divide 14 by 7, gives 2 lbs. for the requisite power.

Of the third kind of Lever.—It is said to be a lever of the third order, when the power is applied between the fulcrum and the resistance, and its effect is determined in the same manner as both of the preceding kinds. *Fig.* 56 represents a lever of this kind; A B the length, equal to 10 feet or 10 inches; F the inverted fulcrum; W a weight of 3 suspended from the end of the lever or 10th division; P a power of 10, pulling up at the third division from the fulcrum; then according to this arrangement, the momenta of these two opposite forces are equal $10 \times 3 = 3 \times 10$; so that in all cases of the lever, the same rule is applied to determine the power requisite to raise any given weight.

Various Combinations of Levers may be employed, the power of one, multiplied into that of the other on which it acts, being their united power.

Plate III. *Fig.* 57 represents a compound lever, each of different powers; F the fulcrums; the lever A B has a power of 3 to 1, from A to the fulcrum being 1-4th of its length. The inverted lever A C bears against the fulcrum at the distance of 2-5ths of its length from C, giving a power of 2 to 1; C D, at 1-5th of its length from D, giving a power of 4 to 1; then their united effect is a power of 4 to 1, acted upon by a power of 2 to 1, which is again acted upon by a power of 3 to 1: consequently $4 \times 2 \times 3 = 24$. The power of these three levers is therefore 24 to 1, so that if W be a weight of 24, it will be balanced by P, a power of 1.

From what has now been said respecting the lever, a slight consideration will be

sufficient to shew that if any number of forces be applied to a lever, there will be an equilibrium, when the sum of the opposite momenta are equal.

When any number of forces are perpendicularly applied to a lever, the weight on the fulcrum, when the forces are all in the same direction, is equal to the sum of all these forces, as in the lever of the first order; and when the direction of the weight and power are opposite, the fulcrum suffers a pressure equal to their difference, as in the lever of the second order.

I have considered the lever as an inflexible rod without weight. I shall now consider the effect of the weight of an actual lever. Let A B (*Plate* III. *Fig.* 58) be the length of a lever of the first order, B C the thickness; suppose its weight 20, and of an equal density, such as a log of wood; suppose its power 5 to 1—of course G is its centre of gravity; now the whole weight of the lever is acting in aid of the power, and acting at the second division from the fulcrum as a second power. Let this weight be considered the power in the first instance, then $20 \times 2 = 40$; then, again, if W be 40, the lever will be in equilibrio, and balance the resistance by its own weight; secondly, if we add 40 more weight to the short arm, we will require to suspend a weight of 20 to the second division, or 1-8th part of 40 to the extremity of the lever; the resistance will now be 80, and the weight of the lever being 20, also 20 suspended from its centre of gravity which is at the second division; then $20 + 20 = 40 \times 2 = 80$: therefore if the lever A B weigh 20 lbs., and its power be 5 to 1, then W, a weight of 80 lbs., will be balanced by a power of 8lbs. at B.

To be still more accurate, the centres of gravity and weights of each end of the lever over the fulcrum should be considered. The weight of the short arm multiplied into the distance of its centre of gravity from the fulcrum, added to the resistance, and the weight of the long arm multiplied into the distance of its centre of gravity added to the power. In constructing levers for proving their power experimentally, the centre of gravity is commonly made to coincide with the fulcrum.

In determining the power of complicated levers, particular attention should be paid, not only to the line of direction of the powers, but also to the spot on the machine, to which the proper action of the lever must be referred. In this way some paradoxical appearances of the lever may be explained.

Two equal weights, suspended from the two arms of a simple lever, will be in equilibrio when the two arms of the lever are of equal length, and if it be made to vibrate, the space passed through by each will be equal, and also their velocities. These conditions must always be fulfilled in the true balance. It follows, therefore, *from these*, that two equal weights will not balance each other when suspended from unequal arms of a simple lever; but if a machine or complicated lever be so contrived that any weights placed at unequal distances from the centre of motion of the lever, have equal velocities, it follows that two equal weights may be placed at unequal distances from the centre of motion, and yet balance each other in every respect.

Dr. Olinthus Gregory ascribes this invention to Desaguiliers, and states, that from undue attention to the spot on the lever or machine, to which its proper action should be referred, many persons have wasted time and money in constructing various kinds of machines, in the hope of discovering a perpetual motion!!! The contrivance referred

to is exhibited in *Plate* III. *Fig.* 59. A B represents the top of a table, C D an upright standard, E F a balance with equal arms, G H another of equal length; they are made to turn freely on the joints I J. Their extremities are connected by the pieces E G and F H with moveable joints at these connections, so that the figure may assume any varying parallelograms, as *a b c d*. On the vertical connecting rods are fixed the pieces N M and L K, and from N and L are suspended two equal weights W and W′. The machine being left to itself, it will be found that these two weights will balance each other in every position; for in consequence of the bar to which they are suspended being firmly fixed in the vertical connecting pieces, the weights will act as if suspended from the two ends of the lever E and F. Now if the machine be brought into the position represented by the dotted lines *a b c d*, the weights *w* and *w′* will have described equal arches; and as they are both at rest or in motion at the same time, their velocities must be also equal, consequently the condition that is required for an equilibrium is not violated, although the weights are placed at unequal distances from the centre of motion.

Of the Wheel and Axle.—The wheel and axle are formed by fixing a circular plane on a cylindric axis, the centres of both coinciding. The power acts on the circumference of the wheel; the weight is attached to a rope which winds round the axle.

An equilibrium in this machine takes place, when the radius of the wheel, multiplied into the power, is equal to the radius of the axle multiplied into the weight; or when the power and weight are inversely as the radius of the circle to which they are applied. Supposing the power and weight to act at right angles to the same radius; let *a b* (*Plate* III. *Fig.* 60) be the wheel and *d c* the axle; let the semi-diameter of the axle $dc = 1$, and the semi-diameter of the wheel $ac = 4$; then by the principle of the lever we have a power of 4 to 1; so that if W be a weight of 8 lbs. suspended from the circumference of the axle, *m* must be a power of 2 lbs. attached to the circumference of the wheel to sustain the weight, and an equilibrium will be obtained between the power and the weight. Now, as the power and weight are inversely proportional to the diameters of the wheel and axle, so are they to the circumference of the circles described by their *places* of suspension; because if the power acts at the extremity of a handspike inserted into the axle, the distance of that extremity from the centre of the axle is to be considered the radius of the wheel. It is necessary to observe, that the law of the vertical velocities of the power and weight is the same here as in the lever; for if the weight W be raised 1 foot, the power will have descended 4 feet, and their respective velocities will be in the same proportion. The winch and the capstan, and all similar machines, are constructed on this principle, and are only different modifications of the wheel and axle, as are also all combinations of wheels and pinions used in machinery, reducible to the wheel and axle.

Of the Pulley.—The pulley is a wheel which revolves on an axis, having a notch or groove cut round its circumference, into which the cord or rope lies in passing over the sheve or wheel. The axis of the pulley may either be fixed or moveable. A fixed pulley does not move out of its place; a moveable pulley rises with the weight.

A fixed pulley gives no mechanical advantage to the power, but merely serves to change its direction. Thus the pulley No. 1 (*Plate* III. *Fig.* 61) is a simple fixed pul-

ley. If a cord be passed over it, equal weights must be attached to each end to obtain the equilibrium; for the perpendicular ascent of the one will be equal to the perpendicular descent of the other. The velocity with which the power moves faster than the weight, is the measure of the advantage gained by the machine, with the simple fixed pulley; this is nothing—therefore no power is gained, but merely a change of the direction of the motion. In system No. 2, one end of the cord is made fast to the beam, the other passes through the moveable blocks which are attached to the weight, and then passing over a fixed block at the beam, the power P is attached to it. Now, it has been seen that the fixed pulley at the beam gains no power, but by the principle of the second kind of lever, the weight hangs in the middle between the fulcrum and the power; the power is therefore able to balance a weight twice as great as itself. Now, the principle of the vertical velocities of the power and weight determines the effect of all machines for raising heavy bodies. It will also be observed, that in this machine, the power is to the weight inversely as their respective velocities; for if the weight be raised 1 foot, the power will have descended two feet in the same time. The weight being 2, its velocity is 1; the power being 1, its velocity is 2. Pulleys 3 and 4 have each two moveable blocks or sheves. Their power is therefore 4 to 1; and for every foot that the weight is raised, the power will descend four feet in the same time. No. 3 is called a fiddle block, and No. 4 a double-sheved block. It is the same thing whether the sheves of the moveable blocks turn on the same or different centres, or whether their diameters are equal or not.

For a better understanding of the principle of the pulley, let it be required to construct a system of pulleys, having a power of 16 to 1, or such that 1 lb. will balance 16 lb. acting as a weight. This may be effected by various combinations or arrangements of single pulleys; and as they all act upon the same principle, I shall select the following:—*Plate* III. *Fig.* 62. Fix one end of a rope or cord to the beam; pass the other under the pulley No. 1, which is hooked on to the weight of 16 lbs., by which arrangement the weight will be divided by the two parts of the cord, the strain on the cord at each side of the block or pulley 1 being 8 lbs. Now if we attach another pulley No. 2, to the end of the cord passing under it, the cord 4, 4, which is the weight of 8 lbs., again divided in two equal parts of 4 lbs. by means of the pulley No. 2; again the 4 lbs. is divided by the pulley No. 3 into two parts of 2 and 2 lbs. each; and lastly, this 2 lbs. is again divided by pulley No. 4, and the cord which passes under this last is taken up over a fixed pulley at the beam, to the end of which is attached the weight of 1 lb., which holds it in equilibrio. By this arrangement, if a weight of 16 lbs. be raised one foot, the power will descend 16 feet, and so on.

This combination would be found very inconvenient and disadvantageous in practice, as the upper pulley would soon come in contact with the beam; and of course the weight could not be hoisted so close up as by a better arrangement of the pulleys for that purpose, as by putting all the pulleys on one axis, forming a four-sheved block, also a four-sheve fixed block attached to the beam—it being the moveable pulleys which confer the power, similar to the principle of the lever of the second order, which is as the distance of the weight from the fulcrum to the distance of the power from the same, so is the power to the weight; and as the weight, suspended by a moveable

pulley when the cords are drawn parallel, is in the middle between the fulcrum and the power, the power is to the weight as 2 to 1. The common rule is to divide the weight by twice the number of moveable pulleys; the quotient is the requisite power. Or when the power and weight are given, and the number of moveable pulleys wanted, divide the weight by the power, and half the quotient is the number of moveable pulleys, or sheves, in the moveable block.

Example.—Given the weight 600, to be raised by two purchase blocks, five sheves in the moveable block—Required the power? Then $5 \times 2 = 10$, and $\frac{600}{10} = 60$, the power required to sustain the equilibrium, and adding $\frac{1}{10}$th part to overcome the friction and rigidity of the ropes, the power sufficient is 66.

Again: Given the power 60, and the weight to be raised 600—Required the number of moveable pulleys or sheves in the moveable block? Then $\frac{600}{60} = 10$, and $\frac{10}{2} = 5$, the number of sheves in the moveable block.

In the case of the last system (*Fig.* 62), dividing the weight by four times the number of moveable pulleys gives the power; and when the power and weight are given, and the number of moveable pulleys required, then take 1-4th of the quotient of the weight divided by the power for the number of pulleys.

The above examples explain the general principles of the pulley, and are sufficient for the calculation of the powers of all sorts and combinations of blocks, tackles, &c.

Of the Inclined Plane.—An inclined plane is a sloping or diagonal plane, forming any angle with an horizontal plane. It is used for rolling up heavy bodies to any height, and various other purposes. The mechanical advantage of the inclined plane is simply as the length of the plane to its greatest perpendicular height, the weight laid on it being to its force of descent as radius to the sine of the inclination of the plane.

If W (*Plate* IV. *Fig.* 63) be a weight of 2, and the length of the plane A B be twice its greatest perpendicular height, it will be held in equilibrio by P, a power of 1 lb.; and by the addition of a very little more force at P, will be drawn up the plane. When a body is to be raised by means of the inclined plane, it should always be drawn or pushed, so that the line of direction of the power be parallel to the plane, and at the height of the centre of gravity of the body.

In the inclined plane, the velocities of the power and weights are equal; but observe, that in this case also, for every increase of the power there is a corresponding loss of time. If two men can roll a body up an inclined plane to a given height in a certain time, then to increase the power, if the plane be constructed of double the former length, and rising to the same height, then one man will be able to roll up the body; but as he will have twice as far to roll it, he will take double the time.

In *Fig.* 63, where the body is held on the plane by the action of a small weight hung over the pulley at C, although the actual velocity of the power and weights are the same, yet their perpendicular ascents and descents are different; for if the weight W be raised perpendicularly to the extent of one foot, the power P will have descended perpendicularly 2 feet. This figure represents the inclined plane as used for making experiments, such as finding the angle of repose of different bodies, of different forms,

of different inclinations of the plane, &c. The graduated quadrant fixed on the machine is for determining the angles of inclination.

The power of the inclined plane is easily determined, being simply as the length of the plane to its perpendicular height; therefore a body may be drawn up an inclined plane, that is, four times its perpendicular height, by one-fourth of the power necessary to lift it perpendicularly up; but there will be a corresponding loss of time.

Some bodies, placed on an inclined plane, roll or tumble down; while others will slide down the plane. This is explained by *Fig.* 64. The body A slides down because the vertical line, passing through its centre of gravity *c*, falls within the base, while the same line in body B falls without its base in every position; it therefore rolls down the plane at the angle of inclination represented.

All bodies, when allowed to move freely, endeavour to bring their centres of gravity to the lowest place possible; consequently a body of a particular form may be made to appear as if rolling up an inclined plane, while at the same time its centre of gravity is descending. The plane for this purpose is formed of two vertical thin boards joined like the top of the letter A, or the two sides of a triangle; the upper edges rising from the angular point, the body formed of two cones joined together at their basis, and when laid upon the lower end of the plane, its centre of gravity begins to descend, and the body appears to roll up the plane.

Of the Wedge.—The wedge is a triangular prism of wood or metal, and is used for various purposes, either to raise heavy bodies, or press them closely together. Mathematicians consider the wedge the most difficult of all the mechanical powers in forming a theory of it. Its power has been generally illustrated as in splitting timber. I have never seen any statement of the weights an ordinary mechanic is able to raise, by means of wedges of different powers, which considerations involve the principles of percussion in regard to the blows of the mallet or hammer.

It is well known that a wedge, loaded with a vast weight, will scarcely have any effect in splitting timber, whereas, by giving it a blow with a hammer, it will penetrate into a very hard substance. When timber is split by a wedge, the split generally extends beyond its point considerably, and the sides consequently form a more acute angle than the wedge, or it forms as it were a new and more powerful wedge, its length being equal to the split, and its base the breadth of the wedge. Considering the subject in this view, the new-formed wedge is resolved into two distinct forces, the one acting in the direction of the split or cleft, which tends to thrust it forward, and the other perpendicular to that direction which tends to tear it asunder—the power of the wedge for this purpose being as twice the sine of half the verticul angle (*Plate* IV. *Fig.* 65), or sine of the angle A C B; and after the split, before the second blow, as twice the cosine of the angle contained between the side of the wedge and the split, as 2 cosine *e g*, and 2 sine *e f*. All wedges, however, are more or less powerful, in proportion to the obliquity of their sides, and hence it becomes the same as the inclined plane; therefore the power of a wedge is simply as its length to its thickness at the head.

Of the Screw.—The screw consists of two parts, the male and female. It is formed by the spiral windings of the hypothenuse of a triangle, wound round a cylinder; at

these windings are formed projecting edges round the surface of the cylinder, which is either wood or iron, the interval between the projections being equal to their thickness. The female part is formed by making corresponding projections round the inside of a hollow cylinder, whose diameter is equal to the diameter of the male screw, including the thickness of the thread. Now, as the projections wind round both the male and female screw in a spiral manner from bottom to top, if one of them is turned round, a change in their positions takes place, by the spiral planes sliding on each other. The female part is generally fixed in a box, and the male screw, which is the long one, rises, ascends, or descends through a space of perpendicular height, equal to the distance between the threads, at every revolution.

The screw in itself is a simple machine, but as the lever is employed to turn it round, it may be said to be made up of two powers, the lever and the inclined plane.

In estimating the power of the screw, say—as the circumference of the circle generated by the handle or lever by which it is turned round, is to the distance between the threads; so is the power to the weight which it will raise. The truth of this will appear from a consideration of the velocity of the power and weight. If the distance between the threads be half an inch, and the circumference of the circle described by the end of the lever, by which it is turned, be 100 half-inches, it is evident that while the weight has been raised one half-inch, the lever has made a complete revolution, and passed through a space of 100 half-inches; then the velocity of the power and weight being as their spaces passed through in the same time; and the power of the machine as the excess of the velocity of the power over that of the weight. If a weight of 800 is to be raised by this screw, a power of 8 applied to the extremity of the lever would be sufficient, of course making an addition to the power to overcome the friction. The friction of the screw is very great, and next to the wedge. In common screws, the friction is able to sustain the weight after the power is withdrawn from the lever or handle. It is found by experiment, that the angle of repose for iron on iron is 16 degrees; therefore, if the threads of a screw have their angles of inclination less than this, the screw will hold the weight at any place. Bnt if the screw be well oiled, and in good working order, it will not hold the weight at a less angle of inclination of the windings of the threads.

Of the Funicular Machine.—When a body is fixed to two or more ropes passing over pulleys, and is sustained by the application of a power exerted in a transverse manner at the middle of the ropes, the funicular machine is constructed; and the force is the more powerful in the inverse ratio of the sines of the angles of the ropes, with the direction of the weights.

The principle of the funicular machine will be more easily understood by the name of Swifters, which the sailors employ to stretch the rigging or any other ropes. By means of this contrivance, a very great weight may be moved or raised a little; for if one end of the rope be made fast to a fixture, and the other be taken over a pulley and attached to a weight, then a power applied in the middle of the rope, acting at right angles to its length, will deflect it, and so draw up the weight to a certain extent; but observe, that as the deflection increases, the power will diminish in the same proportion.

Seafaring people are all aware of these powers experimentally, and therefore any farther observations on the subject are unnecessary.

The Hydraulic Press will be explained in a following chapter on the Equilibrium and Pressure of Fluids,—it being constructed on the principles of Hydrostatics.

CHAPTER III.

ON THE STRENGTH OF MATERIALS.

Before proceeding to consider the strength of Timber, I propose to select a few short observations on the properties of the different kinds which are generally employed in Architectural Structures, and Mr. P. Nicholson's observations on this subject will in part be sufficient for our purpose.

Observations on the Qualities of particular kinds of Timber, &c.

Of the Oak.—For selecting oak timber of the greatest strength and durability, the criterion is to seek it on that soil which has raised it slowly. For it is universally found that plants of almost every description which are quickly raised up, have a soft and flabby texture, for these have not had sufficient time to acquire that density and cohesive strength, which trees of a slower growth are known to possess. This remark, however, cannot be said to be always a fair or safe criterion, because there are particular soils, particularly exposed, where trees of oak have acquired a strength and hardness sufficient to withstand great strains, and which have been known to spring up into lofty trees in a very few years—as, for instance, the oak on the lands of Roxburgh in Scotland, which is allowed to be the best oak raised in Britain. But it must be observed, that a considerable difference will always be found in woods even of the same forest, according to their particular exposures. The strength of oak, and indeed almost all kinds of wood, is mostly always as the density of the fibres.

The time of cutting down is believed to have considerable effect; and it is said that oak, if felled in the winter time, would not only last longer, but possess a greater degree of strength; but as this is an unfavourable time for stripping off the bark, which is of considerable value to the owner, it seldom happens that oak trees are cut down in winter. The most proper time, in order to turn the bark to the best advantage, is to fell the tree in the spring, just after the leaf has begun to appear.

The progress of decay, in trees that have been cut down, commences first at the outside, and, in a more or less perceptible manner according to the situation in which the tree is placed, proceeds towards the heart; but this is in trees which were in a healthy state when cut down: for the reverse of this takes place with old trees—the heart or centre part is often considerably decayed, while the outer is apparently fresh and in a

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healthy state—hence the utility of examining the section of the tree, both at the top and root end.

The best method of seasoning oak is much disputed; it certainly requires time, but where this cannot be allowed, boiling or stoving is the only alternative,—perhaps the safest and best. I am of opinion that a stoved plank will not last equal to a boiled one—well-seasoned plank, bent over a fire, I have never known take the dry rot.

For the purposes of shipbuilding, oak is brought from foreign countries; but in general the British oak is preferable to all others, African or Van Diemen oak not excepted.

Beech and Elm.—The woods which are the produce of this country, and which are the next in use to oak in shipbuilding, are *Beech* and *Elm*, but both are much inferior to oak. Of beech there are three kinds—the black, brown, and white. Beech is said to arrive at the greatest perfection on such grounds as are not of the richest or heaviest kind. According to Barlow's experiments, its cohesive strength is to oak as 11,500 lbs. is to 10,000 lbs. on an inch section; and its transverse strength as 593 to 544½ lbs. on a two-inch section, seven feet between the supports; the cohesive strength of fir of the same section is 12,000 lbs., and its transverse strength 440 lbs.; so that although fir is stronger when pulled directly in its length way, yet it is weaker in its transverse strains. But the beech is badly adapted for beams, because any partial wetting speedily brings on the dampness and rot; it is also very subject to be destroyed by worms. But notwithstanding this unfitness for some purposes, there are many different uses to which beech is applied with advantage, for if it is kept under water, it is exceedingly durable: accordingly it is used in shipbuilding chiefly for keels and the lower timbers or bottom planks. The beech tree is found in great perfection in several parts of Scotland, as also the elm; but these seem to thrive best upon opposite soils. A rich and loamy soil generally produces the best elms.

Of the Scotch Elm.—This seldom can be got of a proper size for working to those purposes to which it could be properly applied in shipbuilding. It is of a hard splitty nature.

English Elm is preferable to the Scotch, and may be considered nearly equal to Scotch beech.

American Elm.—A great advantage to the shipbuilding in this country (Britain) is the introduction of foreign timber, and that imported from America will not be superseded by any of the woods from the Northern parts of Europe. The American elm is in general excellent timber—that which is brought from Canada, commonly called Canadian white elm, is, in my opinion, preferable to all others. It makes excellent keels—it is of a very close tough nature, and is not easily split.

Ash is a species of wood very plentiful, and of extensive use for agricultural purposes; yet it is seldom or never used by the shipwrights, except for tool-handles, handspikes, or the like. The ash tree grows to a great size; it requires a clayey soil. It lasts long as tool-handles, *cart-trams*, or any such like purpose where it is kept knocking about, or kept clean; but if it is used for water-wheels or the like, which are sometimes going and sometimes not in the summer season, it decays the soonest of any wood we know of.

Birch.—The birch which grows in Scotland is what is called white or yellow birch. It sprouts up very fast. It is tough, but will not stand the weather any length of time.

The American birch is of good quality; it is strong, and can be procured in great logs. The brown birch is figured with dapples, and is much used for cabinet-work.

Poplar is liable to the same objections as beech.

The *Aspen* resembles the poplar. It is soft—it lasts a little better when exposed to the weather; but neither of these woods are used in shipbuilding. There is also a variety of other hard woods of this country, which possess nearly the same properties, and are therefore little used in carpentry.

A few of the principal timbers of vessels have been for sometime past made of *African Oak.* It seems to be well liked, and is a strong hard wood; it is very cross-grained, and is expensive to work, especially as plank; yet it has this particular good property in addition to being very durable—it clings but little. But with these good properties, it possesses very bad ones, *i.e.* it is easily split—indeed, it is almost impossible to fasten it properly, for any bolt near the end, if sufficiently tight, splits it. It is very heavy: on this account, it should not be much used for beams or any part of the upper-works of vessels; its weight being more than is generally supposed, tends to destroy the stability of the vessel.

A very strong kind of wood has lately been imported from Van Dieman's Land, called *Sapadella;* it makes excellent treenails, and is very heavy and close in the grain.

In directing our attention to the *Fir,* a most valuable and useful timber, we first notice the larch, the produce of this country, which possesses many properties peculiar to itself, seeming to be stronger and more durable than most of the other firs, so far as has as yet been ascertained; indeed, for the purposes of shipbuilding, we consider it nearest to that of oak, in comparison to any of the other woods of the produce of Britain. There must be considerable difference in the quality of the larch, according to the nature of the soil on which it is produced; and that produced on the estate of his Grace the Duke of Atholl is allowed to be of excellent quality. Several vessels of considerable size have been constructed of this timber, and have been found to give every satisfaction. Fir is common in almost all Northern countries, as Norway, Russia, Prussia, Sweden, North America, and North Britain; and of the firs of these countries there are several kinds.

Norway Fir is not greatly used in the construction of ships in Britain, except for masts and spars.

Russian and *Prussian Fir,* generally known by the names of Memel, Dantzic, and Riga fir, is of very extensive use. The Memel is the best for general purposes. Riga spars is the best masting-timber. The Memel and Dantzic timber may be, and is used for the bottom planks of vessels; steam-boats are generally planked with it I have known a Memel bottom to last twenty years, at which time it seemed nearly as good as the first day.

North American Fir is generally softer than the Baltic timber; it is also more free from knots, and of course is much used for the finishing-timber of houses; and the kind which answers best for panneling and mouldings is called yellow pine. This same

kind makes excellent deck-plank, particularly for steam-boats and vessels exposed to a hot climate. But if it is used as ceiling-plank, near the bow and stern, where it is excluded from the air, it rots uncommonly soon.

On the Ultimate and Comparative Strength of Timber, Iron, and Rope.

1*st, On the ultimate Strength of Timber.*—It is of the utmost importance, that the persons entrusted with the building and construction of houses, ships, or such like mechanical erections, should have not only a knowledge of the value of the materials with which they are to work, but also of those principles which would enable them to apply it to the best possible advantage—to proportion the various pieces of which the structure is to be composed, so that every beam or rafter shall be sufficiently strong to withstand the strains to which they may be exposed—and at the same time, that there be no excess of strength and weight, no useless waste of the materials, but that a *maximum* of effect may be obtained from a *minimum* of material. This is the great aim of the skilful mechanic. Experience has long been the sole instructor of the mechanic, but science is now lending its aid, by demonstrating the extent and direction of those forces to which the materials of heavy buildings are exposed, and deducing, from mathematical investigations, rules and theories for proportioning the strength of materials.

The shipbuilder, more than any other, must look to experience for that knowledge which cannot be fixed by determinate rules, or discovered by abstract research. A ship is a structure of such a form, and exposed to so many various and unequal strains, that even although we knew the amount of the whole, it would be impossible, even for the most able mathematician, to measure the effects on all the various pieces of which she is composed. Yet at the same time he will be greatly assisted in practice by a knowledge of the strength of the different kinds of timber, and of rules for comparing the strength of pieces of different dimensions.

I shall, in the first place, give the results of some of the best set of experiments on the strength of timber. In the second, offer some practical rules for determining the comparative strengths, and also a few observations on the subject. From a mean derived from a number of experiments, it is found that the strength of direct cohesion on a square inch of the following kinds of wood is—

	Lbs.		Lbs.		Lbs.
Box,	20,000	African oak,	12,540	Oak (British),	10,000
Ash,	17,000	Fir,	12,000	Pear,	9,800
Teak,	15,000	Beech,	11,500	Mahogany,	8,000

The above strengths (with the exception of the African oak), as also the following results, were found by Mr. Barlow, and may be considered as being very near the main strengths of the different kinds of wood. The strength of the African oak I found myself from some experiments made for that purpose, as it seems not to have been tried by Mr. Barlow.

Pieces of the following kinds of wood, seven feet long by two inches square, supported on props at the ends, were broke with the annexed weights applied in the middle :—

	Lbs.		Lbs.		Lbs.
Teak,	938	Ash,	772	Larch—mean of four specimens,	426.5
Poon,	846	Beech,	593	Mar Forest fir,	436
English oak, 450 and 639—mean	544.5	Elm,	386	Third specimen of larch,	501
		Pitch pine,	622	Norway spar, six feet long by two inches square,	651
African oak,	500	Red ditto,	511		
Canadian oak,	673	New England fir,	420		
Dantzic oak,	560	Riga ditto—mean of two experiments,	444.5		
Adriatic oak,	526				

The force necessary to tear asunder a square inch section of the different kinds of wood, according to the experiments of Muschenbroek, is as follows :—

	Lbs.		Lbs.		Lbs.
Locust tree,	20,100	Ash,	12,000	Fir,	8,330
Beech and oak,	17,500	Plum,	11,800	Walnut,	8,130
Orange tree,	15,500	Elder,	10,000	Pitch pine,	7,650
Alder ditto,	13,900	Pomegranate,	9,750	Cypress,	6,000
Elm,	13,200	Lemon,	9,250	Poplar,	5,500
Willow,	12,500	Tamarind,	8,750	Cedar,	4,880

The following Table contains the substance of Buffon's excellent experiments on the transverse strength of square oak beams :—

TABLE,

Containing the Results of Buffon's Experiments on the Transverse Strength of Square Oak Beams.

Number of Experiments.	Length of the Beams.		Side of the Beams.	Weight of the Pieces, in Lbs.	Weight which broke the Beams, in Lbs.	Deflection before cracking, in Inches.
Mean of 1 & 2	7 feet	6 in.	... ...	62.40	5716	4.14
" 3 & 4	8	6.8	... ...	71.48	4896	4.50
" 5 & 6	9	7.7	4.28 inches.	80.12	4325.5	5.53
" 7 & 8	10	8.5	... ...	89.30	3892	6.60
" 9 & 10	12	10.3	... ...	106.52	3227.5	7.50
" 11 & 12	7	6	... ...	98.23	12401.5	2.67
" 13 & 14	8	6	... ...	110.83	10532	2.98
15, 16, & 17	9	7.7	... ...	141.85	8939	3.73
18, 19, & 20	10	8.5	... ...	140.08	7666.1	3.80
" 21 & 22	12	10.3	... ...	166.79	6536.5	6.02
" 23 & 24	15	0.0	5.35 inches.	190.46	5703	8.70
" 25 & 26	17	1.7	... ...	222.74	4730.5	8.69
" 27 & 28	19	3.4	... ...	249.11	3641	8.65
" 29 & 30	21	5.1	... ...	281.41	3469.5	10.08
" 31 & 32	25	8.6	... ...	331.95	2326.5	11.96
" 33 & 34	30	0.0	... ...	378.54	1909	21.64

Table of the Results of Buffon's Experiments—(continued.)

Number of Experiments.	Length of the Beams.		Side of the Beams.	Weight of the Pieces, in Lbs.	Weight which broke the Beams, in Lbs.	Deflection before cracking, in Inches.
Mean of 35 & 36	7 feet	6 in.	... ...	133.96	20392	
" 37 & 38	8	6	... ...	158.72	16705.5	2.54
" 39 & 40	9	7.7	... ...	177.82	14040	2.75
" 41 & 42	10	8.5	... ...	201.24	12105	3.47
" 43 & 44	12	10.3	6.43 inches.	239.43	9792	4.33
" 45 & 46	15	0.0	... ...	273.86	8043	4.50
" 47 & 48	17	1.7	... ...	315.83	6846	6.07
" 49 & 50	19	3.4	... ...	257.80	5986	8.52
" 51 & 52	21	5.1	... ...	406.11	5143	9.81
" 53 & 54	8	6.8	... ...	219.52	28033	2.81
" 55 & 56	9	7.7	... ...	243.30	24048.5	3.21
" 57 & 58	10	8.5	... ...	277.24	20957	2.97
" 59 & 60	12	10.3	7.5 inches.	324.44	17405.5	3.34
" 61 & 62	15	0.0		379.86	14231	4.43
" 63 & 64	17	1.7	... ...	435.28	11836.5	5.39
" 65 & 66	19	3.4	... ...	488.55	10138	6.07
" 67 & 68	21	5.1	... ...	654.00	8904	8.74
" 69 & 70	10	8.5	... ...	356.19	29312	2.81
" 71 & 72	12	10.3	... ...	426.41	24136.5	3.11
" 73 & 74	15	0.0	8.57 inches.	495.00	21234.5	3.74
" 75 & 76	17	1.7		564.42	17620.5	4.41
" 77 & 78	19	3.4	... ...	638.87	14163.5	4.59
" 79 & 80	21	5.1	... ...	711.28	12899	6.69

We have considerably abridged the above Table, by taking the mean weight and strengths of those pieces which were of the same dimensions. The timber employed for these experiments was in its unseasoned state, it being cut down, squared the second day, and experimented on the third. In this state, it is generally stronger than after it has been cut some time.

The experiments of Colonel Beaufoy also furnish us with the absolute strength of the four following woods. The pieces experimented were firmly fixed in a mortice at the one end, and on the other the weights were hung.

Length without the Fulcrum, 4 feet; the pieces were each 2 inches square.	Dantzic Oak,.........167 lbs.......Spec. gr. 854
	Riga Fir, ...202 lbs.......Spec. gr. 537
	Pitch Pine,............272 lbs.......
	English Oak,.........258 lbs.......Spec. gr. 922
	Ditto, ...211 lbs.......
	2) 469
	English Oak,......234.5, mean of the two last.

It is generally estimated, that two-thirds of the weight which is sufficient to break a beam, when first laid on it, will very sensibly impair its strength; and in a little time, perhaps two or three months, will cause it to give way. One half of the greatest weight may be borne by the beam for a great length of time, but it will produce a corresponding degree of curvature. One-third of the breaking weight will scarcely produce any

sensible effect beyond that of a slight degree of curvature, and the beam will recover its former straight position again when the load is removed, even although it may have been loaded for many months. One-fourth of the breaking weight may be borne for any length of time (at least until the material itself is decayed with age) without producing any visible deflection of the beam.

As it is often required to cut the strongest rectangular beam out of a tree of given diameter, if we make the sides such, that the square of the breadth, depth, and diameter of the tree, be nearly as the numbers 1, 2, and 3, we shall have the strongest rectangular beam that can be cut out of the said tree. As A B C D (*Plate* IV. *Fig.* 66) may be supposed the section of the tree, and the rectangular figure inscribed within it the beam, having its breadth A B $= 10$, depth B C $= 14.2$, and diameter of the tree B D $= 17.5$; then

$$10 \times 10 = 100$$
$$14.2 \times 14.2 = 201$$
$$17.5 \times 17.5 = 306.$$

The following is the method of finding the section:—divide the diameter D B into three equal parts; from each of these divisions draw the perpendicular to the diameter, as 1 C, 2 A; join A B and D C parallel to A B; also join A D and B C; then will A B C D be the rectangle required, and have its sides nearly in the above proportion. If the diameter of the tree is 20 inches, then the sides of the largest square beam which can be cut out of it is $14\frac{1}{2}$ inches, and the largest rectangular beam cut by the above method has its breadth $11\frac{1}{2}$, and depth $16\frac{1}{2}$ inches. The quantity of timber in each is the depth multiplied by the breadth, the length being the same.

$$14.2 \times 14.2 = 201.6 = \text{contents of the square beam; and}$$
$$16.5 \times 11.5 = 189.7 = \text{contents of the other.}$$
$$\overline{11.9} = \text{difference.}$$

Now it is to be observed, that although the square beam contains the greatest quantity of timber, it is not the strongest of the two for supporting a transverse load, because the strength of beams for this purpose is always found to be as the square of the depth multiplied by the breadth, as will afterwards be fully demonstrated; now taking it in this manner, we shall find that the square beam has the least momentum.

$$16.5^2 = 272.25 \times 11.5 = 3131 = \text{momentum of the deep beam.}$$
$$14.2^2 = 201.6 \times 14.2 = 2862.7 = \text{momentum of the square beam.}$$
$$\overline{268.3} = \text{excess of strength of the deep beam over}$$

the square one, although it contains less timber.

The celebrated philosopher M. Buffon, among others, drew the following conclusion from his experiments:—That the cohesion of the annual circular additions which the tree receives during growth with each other, is much less than that which exists between their own fibres; therefore that a small beam or joist, cut with its depth parallel to the filaments, as A D or B C (*Plate* IV. *Fig.* 67) would be stronger than a beam or joist of the same size cut from the same tree, and whose depth *a d*, crosses the filaments. This difference is generally estimated for oak as 8 to 7.

This fact, if neglected by experimentalists on timber, will render their experiments of less value, and less to be depended upon than might otherwise be, but I believe that it is generally attended to.

While speaking of cutting the strongest pieces from the same tree, Mr. Young observes,*—" If we have a tree whose transverse section is a circle one foot in diameter, from which we wish to take a prismatic beam, we shall obtain the greatest stiffness by making its breadth 6 inches, and its depth 10½; the greatest strength if the breadth is 7 inches, and the depth 9¾; and the greatest resilience by making the beam square." And as Dr. Young observes, in his lecture on passive strength, " these properties may be separately or jointly required in various degrees. For a ceiling, stiffness would be principally desirable—for a door, strength—for the floor of a ball-room, resilience," &c.

It will be our object afterwards to shew the law which regulates the strength of beams; and we may remark here, that the resilience of prismatic beams is simply proportional to the bulk or weight of the beam. The square beam in the above proportions contains the greatest quantity of timber, and of course it is the heaviest; hence its resilience is the greatest. It may easily be conceived, and it will subsequently be more fully noticed, that a beam of twice the length of another of the same diameter and quality, will only support half the weight or pressure of that other. But observe, that it will bear the impulse of a double blow to break it. Thus, if A is the short beam, B one twice the length; then if C is the effect of a blow or stroke which would break beam A, D must be a force equal to C^2 to break beam B; or, which is the same thing, D must, if it is a body of the same weight, fall from a double height in order to break the beam. The author whom we have just quoted, farther observes, " that the stiffness and strength of the beam may be much increased by cutting the tree into four pieces, turning their edges outwards, and uniting them so as to make a hollow beam; but it will require *great strength of union* to make the whole act as one piece, and the resilience of the beam will be rather diminished than increased by the operation. The adoption of the hollow masts and beams, which an ingenious mechanic has lately introduced, requires, therefore, some caution. For where an impulse is to be resisted (that is, a sudden tug or blow), such a mast is no stronger than a solid mast of the same weight, and much weaker than a solid mast of the same diameter. The force of the wind is, however, rather to be considered as constituting a pressure than a finite impulse, except when a sudden squall carries a loose sail before it with considerable velocity." And he farther remarks, " that a similar caution may also be extended to some other attempts to make improvements in naval architecture. It is a common opinion, and perhaps a well-founded one, that flexibility is of great advantage to a ship's sailing. If, therefore, we sacrifice too much resilience to strength, and too much of both to stiffness, we may perhaps create greater evils than those which we wish to avoid."

Mr. Young justly remarks, that the binding of hollow masts must be very firm (great strength of union.) It is long since this invention was proposed, and perhaps would have been generally adopted, but for the impossibility of properly binding the pieces

* Young's Natural Philosophy.

together; for by the expanding and shrinking of the timber from the unequal state of the weather, they soon become loose.

It is of considerable importance for the shipwright to know the mean weight of the different kinds of timber commonly used in shipbuilding; for sometimes it happens that heavy woods cannot be employed for those parts of the hull that are much above water, without considerable disadvantage, for the lighter the upper works are, the better. Heavy timber should be kept as low down in the vessel as possible. Many vessels of excellent proportions are rendered crank from the weight of the material employed above water.

The weight of timber will always depend upon the density of the tree, and the length of time it has been cut, that is, whether it be green or seasoned. Woods, even of the same growth, will vary according to the state of the tree when felled; also the root end is the heaviest in trees of a sound and healthy state. When the tree has been sometime in a state of decay, the reverse of this is the case, the top parts being heaviest.

The excess of weight of a cubic foot near the root, over that of a cubic foot from the top, is about 7 or 8 lbs.

Some woods are said to increase in weight, in seasoning, more than one pound per cubic foot. This anomaly is accounted for by supposing that the wood shrinks in a greater ratio than the diminution of weight occasioned by the drying process.

The following statements of the weight and loss of weight in seasoning, of different kinds of wood, is given by Mr. Tredgold, in his Principles of Carpentry, taken chiefly from Mr. Couch's experiments, published in Barlow's Essay on the Stress and Strength of Timber:—

Kind of Wood.	Weight, when felled, of a Cubic Foot.	Weight, seasoned, of a Cubic Foot.	Shrinkage in Seasoning.
	Pounds.	Pounds.	
Oak (butt end),	69	$47\frac{1}{2}$	$\frac{1}{32}$
Elm,	$58\frac{1}{2}$	$36\frac{1}{2}$	$\frac{1}{44}$
	Weight of a cubic foot when first imported.		
Riga Masts,	42	40	$\frac{1}{72}$
Pitch Pine, American,	47	$46\frac{1}{2}$	$\frac{1}{60}$
Yellow do. do.	$42\frac{1}{2}$	$28\frac{3}{4}$	$\frac{1}{144}$
Spruce do. do.	33	$32\frac{3}{4}$	$\frac{1}{118}$

The following weights have also been found by experiment:—

Kind of Wood.	Weight of a Cubic Foot when green.	Weight of a Cubic Foot after three months' exposure to the air.	Weight of a Cubic Foot when dry.
Oak,	sap-wood 67.0 & 58.7 lbs.	56.18 lbs.	39 to $39\frac{1}{2}$ lbs.
Larch,	53.6 lbs.	51.8 do.	58.3 lbs.
Do. (by another author),	42 do.		31 do.
Walnut,	57.5 do.		38.5 do.
Fir,	33 do.	29.3 do.	25.5 do.

A table of the specific gravity, or the weight of a cubic foot, of a great number of different bodies, and wood of all kinds, will be found in the following chapter on Hydrostatics and Hydraulics.

On the Comparative Strengths of Timber.

Having, by the foregoing tables, exhibited the ultimate strength of the different kinds of timber, we propose now to consider the comparative strength of beams of different dimensions, with which I shall offer a few observations on the different strains to which a beam or any other piece of timber may be exposed. These, distinctly considered, are four—1*st*, A piece of wood, or other substance, may be torn asunder by a stretching force applied in the direction of its length; 2*d*, It may be broken by a transverse force, that is, a force acting at any angle to its length; 3*d*, A beam or upright post may be crushed by a pressure exerted in the direction of its length; 4*th*, It may be twisted or wrenched by a force acting perpendicularly to the end of a lever, the other end of which is inserted into the piece of timber.

The first of these strains is the most simple, as respects the mechanical action of the force applied to produce separation; but it is difficult to submit to experiment, for as the weights necessary to tear asunder any piece of wood in the direction of its length are not increased by the manner of their action, they must be enormous, even for producing fracture on pieces of small dimensions. Several experiments have been made to measure this force, in proportion to the section of the timber exposed, by Muschenbroek, Emerson, Petit Parent, Barlow, and others.

The strength of any beam to resist a force pulling it in the direction of its length, or, as it is termed in science, the strength of direct cohesion of any piece of timber, is in proportion to the area of its smallest section. Hence, if we wish to ascertain what weight will be sufficient to tear asunder a piece of any of the woods mentioned in the foregoing tables, we have only to multiply the weight necessary to tear asunder an inch section, by the number of inches in the section of the given piece.

By inspecting the tables of the strength of different kinds of wood on a section of one inch, we find a considerable difference, of the same kind, by different authors—for example, Mr. Barlow gives the strength of ash 17,000 lbs., which is exactly equal to that of beech and oak, according to Muschenbroek; also the former gives the strength of oak only 10,000 lbs., while the latter gives that of ash to be 12,000 lbs. It will therefore be the safest way in practice to take the mean of that given by these authors.

Thus oak, according to Muschenbroek, = 17,500 lbs.
Do. Do. Barlow, = 10,000 lbs.

$\frac{1}{2}$) 27,500

13,750 lbs. for the mean strength of oak of a section of one inch square.

The force necessary to tear asunder a piece of wood in a short time is much greater than what it can bear for a considerable length of time; also, owing to the inequalities of the material, it will be unsafe in practice to load any piece with more than 1-4th of the weight requisite to tear it asunder. Experiments on the strength of timber are much more irregular than those on metal, there being considerable difference even in the specimens from the same tree. This in some measure accounts for the disagreements in

the experimented strengths given by different authors. Oak breaks with a weight of about six tons per square inch; fir about five tons, and ash about seven tons per square inch.

2d, On the Transverse strain.—This is the most important strain of the whole; its effects are the most to be feared, the mechanical action by which it is produced being such that a small weight in comparison to that required to pull a piece of timber asunder in a longitudinal direction, will produce fracture in pieces of large dimensions when it is applied at right angles to their lengths, in which case the direct cohesion of the fibres is only exerted in an indifferent and partial manner, agreeable to the situation of some fixed principle or mechanical power, such as the lever, the efficacy of which is dependent upon the difference between the compressibility and extensibility of the fibres.

Many theories have been proposed for determining the transverse strength of timber. Many of these have been very erroneous; even the labours of later writers on this subject seem not to have been so successful as they could have wished.

It is generally understood by mechanics and others, that timber or any other tangible material will support transverse strains inversely proportional to their lengths; that is, that a piece twice the length of another, and of the same dimensions, of transverse section, will only bear half of the weight which that other would bear; or, that a piece of four times the length would only bear 1-4th of the weight.

This law, however, is not exactly correct, for the strain actually increases faster than in the simple ratio of the length; for when we increase the length four or five times, we find that the beams will not bear 1-4th or 1-5th of the weight which they would do if that much shorter, even although we consider the weight of the beams themselves as adding to the weight with which they are loaded. When the beams become very long, the decrease of strength becomes very conspicuous, as they sometimes break with their own weight; but in order to make up for this falling off of the strength of long beams, beyond the inverse ratio of the lengths, and for other disadvantages attendant on extraordinary length, the mechanic increases the depth of the beam also in a greater proportion than that required, if the strain increased simply as the length.

In considering the mechanical action of the transverse strain as simply as possible, without professing to carry the reader through a number of particulars, of small moment and of no use in practice, let us proceed, first, to lay it down as an obvious principle, that a piece of wood or a beam will support a certain weight applied to its middle, the beam being rested upon two supports or props, one at each end; that this weight will be more or less in proportion to the quality of the timber, the dimensions and form of the beam, and the distance between the props or points of support. Now, if we have a piece of timber of certain dimensions—it will carry a certain weight; also, if we have another piece of the same length, breadth, and depth, and of the same kind and quality, it will carry an equal weight. Hence, if we lay these two beams side by side, they will carry double the weight, and so continue to bear additional weights in an arithmetical proportion to the number of pieces; and of course a double strength is obtained by a double breadth, a triple strength by a triple breadth, and so on.

We have now laid it down that the strength of beams is affected by an increase or decrease of breadth, singly as the breadth—a double breadth producing a double strength or resistance. We shall next consider the effect of an increase of the depth in the same manner.

If two pieces of equal quality and dimensions are evenly joined and fastened together, the one upon the top of the other, they will not only carry twice the weight, but four times that which one of them would by itself; and in like manner, any number of such pieces fixed one upon the top of another, would continue to bear weights in proportion to the square of their number. Thus a double depth produces a quadruple strength, and so on. The action of the weight or strain in this case is completely different from the former. In the first, the mechanical advantage of the weight on the beam or beams is not diminished, although the breadth or number of beams placed side by side is increased: hence, if two beams are to be broken when laid in this position, there is a double number of fibres to break, while the mechanical action of the weight is the same; therefore a double weight will be necessary to break a beam of double breadth. In the second case, when the beams are fixed one above the other, there is only a double number of fibres to break, but the mechanical action of the weight is reduced one-half of what it is when the beams are laid side by side; therefore, if there are two of them placed the one above the other, it will require four times the weight which one of them would bear, to break them. Now, the strength is as the force requisite to break the beam; therefore, when the length is the same, the strength varies as the breadth multiplied into the square of the depth.

As it may be a little difficult for the learner to trace the mechanical action here mentioned, we shall point it out by a figure. For simplicity, let us assume at present that beams are only flexible at the place of fracture,—that they are sufficiently strong, except at that particular spot,—also, that the fibres are inextensible and incompressible,—and likewise, that the centre of motion about which a beam, supported at the two ends, and loaded in the middle, folds or turns in the moment of breaking, is at the upper edge of the section of fracture, and therefore that every fibre is exerting its force in resisting tension.

Then, let *Fig.* 68, *Plate* IV. represent a beam of any length, breadth, or thickness; say it is 9 inches square; let *Fig.* 69, same *Plate*, be another beam of the same kind and quality, of the same length, but double the depth, $= 18$ inches; let both of these be supported on props T T and T T; let W— and W— be weights proportional to the strength of the beams to which they are applied, that is, as the breadth into the square of the depth. In this example, if W (*Fig.* 68) be one ton, then W′ (*Fig.* 69) will be four tons. In beam 68 there is a certain number of fibres to break; the depth of the beam R S acts as the resisting arm of the lever,—R being the centre of motion, or fulcrum, as it were,—A R being the long arm of the lever, which with the weight produces a force sufficient to tear the fibres asunder at the section of fracture. Now, the beam (*Fig.* 69) is double the depth, and of the same breadth, as *Fig.* 68; it will therefore contain double the number of fibres. The breaking weight must therefore be double on this account; but it must also be double on another account, as the re-

sisting arm R S is double R S, *Fig.* 68, while the long arm of the lever is the same in both: Therefore, by the property of the lever, the cohesion of any fibre (as S S′, *Fig.* 69) will, by acting at twice the distance from the centre R, which the corresponding fibre S S′ (*Fig.* 68) is from its centre of motion, exert a double resistance. Hence, on account of this double resistance, and a double number of fibres exerting tension, the strength of the beam 69 will be to that of *Fig.* 68, as 4 to 1. If another piece of the same dimensions as *Fig.* 68 were laid on *Fig.* 69, the resisting arm R S would be three times that of *Fig.* 68: the number of fibres would also be three times that in 68. The strength in these two cases would then be as 9 to 1, and so on. With respect to the deflection R K in the above case, where the strain is proportional to the resistance, it is inversely as the breadth and cube of the depth; and when the length varies, it is directly as the cube of the length, as may be easily discovered by inspecting the deflections of the beams in Buffon's experiments. See the preceding Table.—If a beam is deflected with a certain weight, it will be deflected twice as much with a double weight. A beam of double the breadth will be deflected only half as much as another of the same length and depth, when loaded with the same weight; but a beam of double the depth, and of the same length and breadth as another, will be deflected only the eighth part of that other with the same weight, or only half as much with four times the weight. If a beam is longer than another, the deflection will be found thus:—As the cube of the one is to its deflection, so is the cube of the other to its deflection. In Buffon's experiments (11 and 12), the beam is 7 feet 6 inches long, and is deflected 2½ inches with 12,499 lbs., and another four times the length (33 and 34), viz. 30 feet long, is deflected 21 inches with 2287 lbs., including the weight of the beams. Then $7.5^3 = 422$, and $30^3 = 27{,}000$, and $422 : 2.5 :: 27{,}000 : 112.3$ inches. Now 2287 is only the 5.4th part of 12,499 lbs.; so that, if we multiply 21 inches by 5.4, we shall have $21 \times 5.4 = 113$ for the deflection by experiment, which nearly agrees with the deflection as calculated.

Rules for the Comparative Strength of Beams.

I shall next give some examples for comparing the strength of beams, and it will be sufficient if we consider them of the same length. Any difference in that dimension will require the addition or subtraction of some part of the proportional strength, to or from itself, and we shall show how this is to be done in practice.

1*st*, Beams of the same length will support weights in proportion to the breadth multiplied into the square of the depth. Then, for convenience, let us call this product the momentum of the beam. Thus, to find the strength or momentum of a beam which is 12 inches square:—$12 \times 12 = 144 = 12^2 \times 12 = 1728 = 12^3$; and the momentum of all equal-sided square timber is just the cube of the side.

Again, to find the momentum of a beam 17 inches deep and 9 inches thick:—$17 \times 17 = 289 = 17^2 \times 9 = 2601 =$ the momentum.

Case Third.—In finding the momentum of a round beam or mast, observe, that as the squares of all the sines of the round only amount to 2-3ds of the momentum of an equal-sided beam whose sides are equal to the diameter of the round, a round beam or

cylinder will only bear 2-3ds of the strain that a square beam will, whose side is equal to the diameter of the round. To find the momentum of a round piece or beam, square the diameter, multiply by 2-3ds of the diameter, and the product will be the momentum. Thus, a round beam is 12 inches in diameter; required, the momentum of its power to support a transverse strain:—$12^2 = 144 \times 8$ (which is 2-3ds of 12) $= 1152$, the momentum.

Problem 1.—*To find the side of an equal-sided beam, that shall be double, triple, or one half the strength of any other equal-sided square beam of a given dimension.*

Rule.—Cube the side of the given beam; double or triple it according as the strength is required, and then take the cube root of the sum for the side of the beam sought.

Example.—Given, an equal-sided square beam of 12 inches; required, the side of another square beam that shall be double the strength?—Then, $12 \times 12 = 144 \times 12 = 1728 \times 2 = 3456 =$ the momentum doubled, $\sqrt[3]{3456} = 15\frac{1}{8}$ inches for the side of a beam of double the strength.

Again, let 12 inches be the side of the given beam; required, the side of another of only half the strength?—Then, $12 \times 12 = 144 \times 12 = 1728$, half the momentum $= 864$, and $\sqrt[3]{864} = 9\frac{1}{2}$ inches, the square of the side of the beam of half the strength.

The above rule is also applicable to all unequal-sided beams, when the sides are to bear the same proportion to each other as those of the given beam, by only observing which way they are to be laid to support the weight or strain, and so calling that the depth. Then, to find the dimensions of any beam that shall be half, double, or triple the strength of another, and its sides to bear the same proportion to each other as the given beam:—Cube the depth of the given beam; take double, triple, or half the momentum, then take the cube root of the sum, and it will be the depth of the beam as required.

Example.—There is a beam 16 inches depth, and 8 inches thick; required, another of half the strength, and its sides to be in the same proportion?—$16 \times 16 = 256 \times 16 = 4096$, one half the cube $= 2048$, the cube root of which is $12\frac{3}{4}$ by $6\frac{3}{8}$ inches, the side.

Again, suppose a beam to be 9 inches deep, and 6 inches thick; it is required to make another of double strength, and to have its sides in the same proportion?—$9 \times 9 = 81 \times 9 = 729 \times 2 = 1458$, the double cube; and $\sqrt[3]{1458} = 11.33$, or $11\frac{3}{8}$ inches deep, by $7\frac{5}{8}$ in breadth.

Problem 2.—*To make a beam, whose sides shall bear any different proportion to each other, such as, that the thickness shall be 2-3ds, $\frac{1}{2}$, 1-3d, or 1-4th of the depth, and of the same or any other comparative strength with the given beam.*

Rule.—Find the momentum of the given beam; add the same proportion of the momentum to itself, that is wanting in the required beam to make it up to a full square. If the thickness of the required beam is to be 2-3ds of its depth, add one half the momentum to itself, then the cube root of the sum will be the depth of the beam required, and of equal strength to the given beam. If the thickness is to be only one-half the depth of the side, the momentum must be doubled; and if it is to be only 1-3d of

the depth, the momentum must be tripled; then the cube root is the depth of a beam of equal strength to the given beam. But if the required beam is to be stronger than the given one, the same proportion of strength which is wanted must be added to the momentum of the given beam.

Example 1*st*.—There is a beam which is 18 inches deep and 9 thick; required, the dimensions of another of equal length and strength, whose thickness shall be 2-3ds of its depth?—$18^2 = 324 \times 9 = 2916 + \frac{1}{2}$ momentum $1458 = 4374$, the cube root of which is 16.35, which is the depth, near $16\frac{3}{8}$ inches, by $10\frac{7}{8}$ inches in breadth, for the dimensions of a beam of equal strength with one of 18 inches deep by 9 inches thick.

Example 2*d*.—Again, let the given beam be 18 inches deep and 9 thick, as before; required, the depth and breadth of another of equal strength, whose thickness shall be 1-3d of its depth?—$18^2 = 324 \times 9 = 2916$ momentum $\times\ 3 = 8748$, the cube root of which is 20.6 for the depth of the side, 1-3d of which is 6.86 for the breadth or thickness = to $20\frac{1}{16}$ by $6\frac{7}{8}$ inches nearly, for the dimensions of a beam of equal strength with the given beam.

Example 3*d*.—There is a beam of 15 inches deep, and 10 inches in thickness; required, the size of another of the same length that shall bear double the weight, and its thickness to be only 1-4th of its depth?—$15 \times 15 = 225 \times 10 = 2250$ momentum $\times\ 2 = 4500$ double momentum $\times\ 4 = 18{,}000$, the cube root of which is 26.20, the depth of the side, by 6.55 the thickness $= 26\frac{1}{4}$ inches by $6\frac{9}{16}$.

Example 4*th*.—There is a square beam of 9 inches; required, the depth and breadth of another of equal strength, whose thickness shall be only 1-5th of its depth?—$9 \times 9 = 81 \times 9 = 729$ momentum $\times\ 5 = 3645$, and $\sqrt[3]{3645} = \frac{15.38}{5} = 3.08$ the breadth, or $15\frac{3}{8}$ by $3\frac{1}{8}$ inches.

Note 1*st*.—When the space over which any required beam is to extend is greater than that of the given beam, or, in other words, if the required beam is to be twice or thrice as long as the given one, before it can be of equal strength, its momentum must not only be double that of the short beam for a double length, but it must also be increased by 1-10th. If a beam is to be three times the length of a given one, and of the same strength, its momentum is found by tripling that of the given beam, and increasing the product by 1-8th. If the required beam is to be four times the length of the given one, its momentum must be that of the given beam multiplied by 4, and increased by 1-5th.

Note 2*d*.—When the required beam is to be broader than it is deep, that additional breadth, which is more than the square of the depth, must be deducted from the momentum of the given beam; which is the reverse of what is done in the other case, where as much is added to the momentum of the given beam as what the thickness of the required beam wants to make up the square of the depth.

PROBLEM 3.—*To make a beam, whose sides shall bear any different proportion to each other, with the breadth greater than the depth, and to bear an equal weight with any given beam.*

This problem should have been involved in the preceding, it being merely the re-

verse of the first part of the operation, *i.e.* before extracting the cube root; at the same time, it will be easier understood from a few separate examples.

The rule is given by note 2d in the last problem; and in this case, the difference between the breadth and depth of the required beam must be deducted in the same proportion from the momentum of the given beam. For instance, if the breadth of the required beam is to be $1\frac{1}{3}$ the depth of its side, it is certain that the additional 1-3d of the depth, when added to the breadth, will then become 1-4th of the breadth; so that if the breadth is to be $1\frac{1}{3}$ of the depth, deduct 1-4th from the momentum of the given beam; if the breadth is to be $1\frac{1}{2}$ the depth, deduct 1-3d from the momentum; and if the breadth is to be double the depth only, take one half of the momentum; if triple, use 1-3d of the momentum, &c. &c. always deducting what is over the square of the depth, as shewn in the following examples; and the cube root of the remainder, after deducting the proportional part of the breadth from the momentum, will be the depth of the side of the beam wanted.

Example 1st.—Given, a beam nine inches square; required, another that shall bear an equal weight, and whose breadth shall be double its depth?—$9^3 = 729$ the momentum, one half of which is 364.5. and $\sqrt[3]{354.5} = 7.14$, which is the depth, the breadth being double $= 7.14 \times 2 = 14.28 = 7\frac{1}{8}$ inches the depth, by $14\frac{1}{4}$ inches the breadth, the dimensions of the required beam, &c.

Example 2d.—There is a beam 12 inches deep and 8 inches thick; required, the depth of another of equal strength, whose breadth shall be one and 1-3d its depth?—

$12 \times 12 = 144 \times 8 = 1152$ mom., deducting $\frac{1}{4} = \frac{1152}{4} = 288$; then $1152 - 288 = 864$;

by extracting the cube root, we obtain 9.52 for the depth, or $9\frac{1}{2}$ inches; the breadth being $1\frac{1}{3}$ of the depth, is 12.69, or near $12\frac{3}{4}$ inches.

Example 3d.—Again, let the given beam be nine inches square; required, the dimensions of one of equal strength, and whose breadth shall be five times its depth?—

$9 \times 9 = 81 \times 9 = 729$ the momentum; then $\frac{729}{5} = 145.4$ one fifth of the momentum;

$\sqrt[3]{145.400} = 5.25$; the depth $5\frac{1}{4}$ and the breadth $26\frac{1}{4}$ inches.

PROBLEM 4.—*To find the depth of any unequal-sided beam of a given thickness, that shall bear an equal weight with any other given beam.*

Rule.—Find the momentum of the given beam, which divide by the thickness of the required beam; then take the square root of the quotient for the depth of the beam sought.

Example 1st.—Given, a beam of 11 inches square; required, the depth of another that shall bear an equal weight, and whose thickness shall be 7 inches?—$11 \times 11 = 121$

$\times 11 = 1331$; then $\frac{1331}{7} = 190.14$, and the square root of 190.14. is 13.78; the depth

of the required beam $13\frac{3}{4}$ inches nearly, by 7 inches in breadth.

Example 2d.—Given, a beam of 12 inches deep and 9 in thickness; required, the depth of another that shall bear an equal weight, and the thickness to be only 5 inches?

—$12 \times 12 = 144 \times 9 = 1296$ the momentum; then $\frac{1296}{5} = 259.20$, the momentum divided by the thickness; the square root of 259.20 is 16.9, near $16\frac{1}{8}$ inches for the depth required.

Example 3d.—Given, a beam 14 inches deep by 7 inches thick; required, the depth of another that shall bear 1-3d more weight, and its thickness be only 6 inches?—$14 \times 14 = 196 \times 7 = 1372 + $ 1-3d of the momentum $= 1829.5 \div 6 = 304.9$, the thickness; then $\sqrt{304.91} = 17.46$, near $17\frac{1}{2}$ inches for the depth sought.

Example 4th.—Required, the depth of a two-inch thick joist, that shall bear equal to one of 6 inches square?—$6 \times 6 = 36 \times 6 = 216$, and $\frac{216}{2} = 108$; $\sqrt{108} = 10.39$, nearly $10\frac{3}{8}$th inches for the depth of the joist?—If the joist is to be $2\frac{1}{2}$ inches thick, divide the momentum by $2\frac{1}{2}$. Thus $2.5)216.0(= 86.4$, the square root of which is 9.29, or $9\frac{1}{4}$ inches.

Note.—When the size of any square beam, that shall be equal in strength to any other rectangular beam, is wanted, take the cube root of its momentum for the side of the square of the required beam.

Problem 5.—*Having the depth given, to find the thickness of any beam that shall bear an equal strain to any other beam of a given dimension.*

Rule.—Find the momentum of the given beam, and divide it by the square of the depth of the proposed beam, and the quotient is the thickness required.

Example 1st.—Given, a beam of 18 inches deep, and 6 inches thick; required, the thickness of a beam which will bear an equal weight, and whose deepness shall be 15 inches?—$18 \times 18 = 324 \times 6 = 1944$; then the depth of the proposed beam $15 \times 15 = 225 = 15^2$ $\frac{1944}{225} = 8.64$, or $8\frac{5}{8}$ inches, the thickness.

Example 2d.—Given, a beam 6 inches square; required, the thickness or breadth of another to bear an equal weight, whose depth shall be 9 inches?—$6 \times 6 = 36 \times 6 = 216 =$ momentum of the given beam; $9 \times 9 = 81$, square of the depth of required beam; $\frac{216}{81} = 2.66$, or nearly $2\frac{2}{3}$ inches, the thickness of the required beam.

Example 3d.—Given, a beam 9 inches square; required, the breadth of another, to bear an equal weight, whose depth shall be only 6 inches?—$9 \times 9 = 81 \times 9 = 729$, momentum of given beam; $6 \times 6 = 36$, square of the depth of required beam; then $\frac{729}{36} = 20.25 = 20\frac{1}{4}$ inches, the breadth of required beam.

Example 4th.—Given, a beam of 14 inches deep, and 8 inches thick; required, the thickness of another, to bear double the weight, and whose depth shall be 16 inches?—$14 \times 14 = 196 \times 8 = 1568 \times 2 = 3136$ the double momentum; $16 \times 16 = 256$, square of the proposed beam; $\frac{3136}{256} = 12.25 = 12\frac{1}{4}$ inches, the thickness required.

Problem 6.—*To find the diameter of a round beam or mast, that shall bear an equal strain to any square beam of a given dimension.*

Note 1st.—To find the comparative strength of round timber to that of square or unequal-sided rectangular beams,—observe, that the squares of all the sines of a round will only amount to 2-3ds of the momentum of a square beam whose side is equal to the diameter of the round; hence it will support little more than 2-3ds of the weight.

Rule.—Cube the side of the given square beam, and to it add half the cube; then the cube root of the sum will be the diameter of a round of equal strength.

Example 1st.—There is a square beam, 12 inches on the side; required, the diameter of a round beam or mast that will bear an equal transverse strain?—$12 \times 12 = 144 \times 12 = 1728$ mom. $+ \frac{1}{2}$ mom. $= 2592$, and $\sqrt[3]{2592} = 13.736$, which is very near $13\frac{3}{4}$ inches for the diameter sought.

Note 2d.—Observe, that the momentum of a square beam is its cube, and that the momentum of any unequal-sided or rectangular beam is the square of the depth multiplied by the breadth.

Example 2d.—There is a beam of 12 inches deep and 6 inches in breadth; required, the diameter of a round beam of equal strength?—$12 \times 12 = 144 \times 6 = 864$ mom. $+ \frac{1}{2}$ mom. $= 1296$, and $\sqrt[3]{1296}$ is 10.9, or nearly 11 inches for the diameter required.

To reverse the preceding question, by case third, is to find the momentum of the round, it being of the same strength as an unequal-sided beam, having its depth equal to the diameter of the round, and the thickness equal to 2-3ds of the diameter.

Example.—There is a round beam whose diameter is $10\frac{9}{10}$ inches; required, the depth of a rectangular beam of equal strength, and whose thickness shall be half its depth?—$10.9 \times 10.9 = 118.81 =$ square of the diameter; 2-3ds of diameter is 7.27.

$$\begin{array}{r} 118.81 \times 7.27 = 863.7487 \text{ momentum of the round.} \\ 2 \\ \hline 1727.4974, \end{array}$$

which may be called 1728, the cube root of which is 12, and the breadth being half the depth $= 6$; hence the answer is, 12 inches deep, and 6 inches thick.

Note 3d.—If the thickness of the beam sought had been given $= 6$ inches, the momentum of the round being 863.7487, which we have called 864; then $\frac{864}{6}$ the thickness $= 144$; the square root of which is 12 for the required depth.

Note 4th.—In these considerations the beams are supposed to consist of a number of parallel fibres equally distributed around the axis, and all presenting an uniform resistance; however, this is not exactly the case, for we know that the layers formed by the annual growth of the tree form as it were so many hollow cylinders into each other, and but slightly adhere together. Now observe, that when a tree is squared into a beam, all the cylinders greater than the circle inscribed in the square of the beam are cut off at the sides; and as the strength of the beam is chiefly owing to that of the entire ligneous cylinders contained within it, those parts of the cylindric layers which form the corners of the beam are supposed to add but very little to the strength;

therefore a round beam or cylinder may fairly be supposed to carry more than 2-3ds of the weight that a square beam of equal diameter will, although its proportional strength, according to the squares of the sines, is only 2-3ds of a square beam.

Having given the above rules and examples for comparing the strength of beams of different dimensions, which I presume will be found of service to all who are connected with the construction of vessels, it must be acknowledged that the hypothesis on which the theory is founded is not truly consistent with known principles; yet as far as relates to the comparison of similarly formed beams, but of different dimensions, these deductions, *i. e.* that when the breadth and depth are the same, the strength varies inversely as the length. When the length and depth are the same (as explained in case first), the strength varies directly as the breadth; and that, when the length and breadth are the same, the strength is as the squares of the depth (case second), are found to agree very nearly with experiment. Although we have only considered the beams as supported at each end, it is obvious that we may apply the same rules with equal confidence in comparing the strength of a given beam to any other, when they are both placed in the same situation, and loaded in the same manner, let the situation and manner of applying the weight be what it may.

The strength of a beam, when fixed with one end in a wall, or when fixed at both, as compared to the same when merely supported at the two ends, the effect of different forms of the transverse section, and when the load is collected at one place, or uniformly distributed throughout the length, &c. will, after we have a little farther considered the first theory, and compared its results with experiments, be our next inquiry, and with which we shall conclude our observations on the strength of timber.

We have observed that the strain on beams increases in a greater ratio than in proportion to the length, or that the strength diminishes faster than in the inverse ratio of the length. Before a correct theory of the strength or stress of timber can be expected, we must consider that the increase of strain beyond that of the length is dependent upon circumstances agreeable to the nature of the material; and that without such are taken into account in mathematical investigations of the subject, we cannot expect to arrive at conclusions on which to found a formula that will furnish results agreeing exactly with experiment. We must first be acquainted with the properties of the bodies or materials exposed to these particular strains.

It will be recollected on what hypothesis we have grounded the theory for the comparative strength of timber:—*First*, That it assumes the beam to be inflexible, and insuperably strong, except at the place of fracture; *secondly*, That the fibres are inextensible and incompressible; *thirdly*, That the beam turns about its uppermost edge in the operation of breaking when supported at both ends, or its lowest point when fixed by one end in a wall, or the like; and *lastly*, That every fibre is exerting its force in resisting tension. Now, with respect to the first of these suppositions, it is clear that no beam of timber is perfectly inflexible, let its dimensions be what they may; for it will assuredly be deflected more or less if a sufficient force is applied for that purpose, and this force will always be less than that which is required to produce fracture; and were the fibres inextensible, this deflection, to which every body is subject before

breaking, could not take place: Hence we must grant, that a body (and particularly a beam of timber), is extensible; and as whatever is capable of being expanded or extended, is also capable of being compressed, it is evident that the fibres of timber are compressible, although we cannot exactly determine the relation of the one to the other. These two opposite properties, existing in one and the same material, will be called upon to resist the effect or weight of any other body from destroying their state of equilibrium and rest, according as that weight is applied, either to crush or tear the beam asunder in the direction of its length. If it subjects the beam to a transverse strain, the resistance is caused by a compound force, made up of the force necessary to tear a part of the beam in the direction of the fibres, which is called the force of direct cohesion, and of the resistance which it presents to compression, which are both overcome when a sufficient weight is applied to produce the fracture; consequently, from consideration of these two powers at the moment of fracture, it is asserted that the beam will not turn upon its edge as the centre of motion or fulcrum. And lastly, our hypothesis supposes every fibre to be exerting a constant and equal resistance, independently of its quantity of extension. This we cannot allow to be correct, more than the others. The theory, however, considering its simplicity and early discovery, is not discreditable to the memory of Galileo, who is said to be the first that connected the subject with geometry, and endeavoured to deduce from pure mathematical principles these rules for computing the strength of timber, according to its dimensions and the strain to which it is commonly exposed, although time and experience have proved it to be defective in some immaterial points; and accordingly other theories have been substituted in its place, into the detail of which we are not prepared to enter. Indeed, although we were, we should be loath to do so, as it would only be swelling our pages with that which the great majority of our readers would consider useless, as they do not seem to lead to results agreeing much better with experiment than the simple theory of Galileo. In the meantime, it may be satisfactory to compare the strength of beams of different dimensions given in the table of Buffon's experiments, by the principles we have already given for the comparative strength of timber. This will shew how far short or above the real strength, as found by experiment, these rules would lead us.

In alluding to the strength of beams, in terms of the length, we mentioned that a beam of four times the length of another, and of the same diameter, would carry only about 1-5th of the weight. Now, by referring to the table, we find that the mean strength of the beams used in experiments 11 and 12 is 12401.5 lbs. These beams were 7 feet 6 inches long by 5.35 inches diameter. Estimating the strength of another beam of the same breadth and depth, but four times the length, according to the above, it should bear about 1-5th of that weight, which is 2480 lbs. The beams used in experiments 33 and 34, were 30 feet long, and of the same depth and thickness, and their mean breaking weight, as stated in the table, is 1909 lbs., making a difference of about 400 lbs.; but if we add the weight of the beams themselves to their breaking weights, there will only be a difference of about 200 lbs. This comparison is sufficient to shew that we have not overrated the strain on a beam of four times the length of another of the same diameter, as it does not carry 1-5th of the weight.

In practice, it seldom happens that we require to consider the proportional strain on one beam from that on another of so different a length as in the above case, and rules deduced from experiments on small pieces cannot be depended on. We therefore consider that we go far enough for the present. By comparing together the strength of beams of a double and triple length, according to the rule given in note 1, problem 2, the reader may satisfy himself that we come sufficiently near to the truth. In that note we say, that when a beam is to be double the length of another, and of the same strength, the momentum of the short beam must be doubled, increased by 1-10th, and taken for the momentum of the long beam; when it is three times the length, the momentum of the short one must be tripled and increased by 1-8th; when four times the length, it must be multiplied by 4, and increased by 1-5th: Therefore it will be the same thing, taken in the reverse manner, if we have the breaking weight of a beam of a certain length and diameter, and wish the breaking weight of another of the same diameter, but of a double or triple length, if we take the 1-half or 1-3d of the breaking weight of the given beam, diminished by 1-10th, or three times the length by 1-8th, the product will be the breaking weight very nearly, as shewn by the following arrangement, where they are compared with the weight found by experiment. See Buffon.

	Experiments taken from	Lengths of the Beams.		Diameter.	Breaking Weights.	Weight of the Pieces.	Breaking Weight, and weight of the Pieces.	Calculated Strength, and that found by Experiment.	
Com-	13 & 14	8 ft.	6 in.	by 5 in.	10,532 lbs.	+ 110 lbs.	= 10,642 lbs. and 10,642 — $\frac{1}{10}$ ÷ 2 =	4,788 lbs.	by rule.
pare	25 & 26	17	0	5	4,730	+ 222	=	4,952 „	by exp.
Com-	11 & 12	7	6	5	12,401	+ 98	= 12,499 lbs. and 12,499 — $\frac{1}{8}$ ÷ 3 =	3,645 „	by rule.
pare	29 & 30	21	6	5	3,469	+ 281	=	3,750 „	by exp.
Com-	11 & 12	7	6	5	12,401	+ 98	= 12,499 lbs. and 12,499 — $\frac{1}{5}$ ÷ 4 =	2,499 „	by rule.
pare	33 & 34	30	0	5	1,909	+ 378	=	2,287 „	by exp.

The small difference between the strength given by the rule, and that found by experiment, is almost unworthy of attention, when we consider the nature of the material, as there will be perhaps more difference in the qualities of the pieces of the same tree.

With respect to the strength of beams, of the same length, being as the breadth multiplied into the square of the depth, we shall find this also to be sufficiently near to the real strength, for any practical application.

For example, let us take the mean strength of the beams 1 and 2 of Buffon's Experiments. Here the length is 7 feet 6 inches, breadth and depth $4\frac{1}{2}$ inches, the breaking weight 5716, and adding the weight of the beam 62 lbs., makes 5778 lbs. From this let us compute the strength of a beam of the same length, but of a different diameter, as 7 feet 6 inches long by $6\frac{1}{2}$ square.

Now all that we have to say is, as the momentum of the small beam is to the momentum of the larger one, so is the strength of the one to the strength of the other; for the strength is as the momentum. Then, as 78.4, the momentum of the small beam, is to 5778 lbs., its ultimate strength, so is 265.8, the momentum of the thick beam, to its ultimate strength; this gives 19,590 lbs., including the weight of the beam. Referring to the table of Buffon's Experiments, we shall find that beams 35 and 36 were 7 feet 6

inches long, and 6.43 inches in thickness; and that they broke with about 20,500 lbs., including their own weight. According to our calculation, it should have been 19,590 lbs., the difference being about 900 lbs.; the beam is therefore stronger by 1-19th part than what the rule would give it. But for this, we have to observe, that it is extremely difficult to ascertain the weight with which a beam actually breaks; also, the curvature increases so fast and irregularly towards the extent of the load, that although the above proportion may vary a little in giving the breaking weight, yet as the weight to which beams are exposed in all common cases does not amount to 1-4th or 1-5th of the weight necessary to break them, this mode of comparing the strength of timber may therefore be adopted in general practice. However, it may be useful to shew a few rules for determining the strength of beams of any length and dimensions. Accordingly, we must first know what weight a given piece of the same wood will support. We have already remarked, that data produced from experiments made on small pieces of timber are not to be entirely depended upon; but having the excellent table of Buffon, we may at all times refer to it for a comparison, and consequently calculate the strength of any beam from the actual strength of a piece of the same timber, 1 foot long and 1 inch square.

It has been found by experiment, that a piece of oak 1 foot long 1 inch square, lying on props at each end, will break with a weight of about 600 lbs. on its middle. Also, that the breadth of any beam, multiplied by the square of the depth, and divided by the weight multiplied by the length, is a constant quantity; and by comparing some of Buffon's experiments, it will be found nearly so.

Thus, Experiments 1 and 2:—Length 7 feet 6 inches, breadth and depth $4\frac{1}{4}$ inches, breaking weight 5716 lbs.; $4.2^2 = 17.6 \times 4.2 = 74$, and $5716 \times 7.5 = 42{,}870$; then $\frac{74.}{42{,}870} = .1726$ constant quantity. And in Experiments 35 and 36, the length is 7.5 feet, breadth and depth 6.4 inches, breaking weight 20,392 lbs.; $6.4^2 = 40.9 \times 6.4 = 261.7$, and $20{,}392 \times 7.5 = 152{,}940$; then $\frac{261.7}{152{,}940} = .1717$ constant quantity;—and so will be found nearly the same for any of the other beams. Now, we have seen from the above, that the breadth multiplied by the square of the depth, and divided by the breaking weight, multiplied by the length of any one beam, is equal to the breadth multiplied by the square of the depth, divided by the breaking weight multiplied by the length of any other beam; consequently an equation is thus formed, from which is found the strength or dimensions of any required beam, agreeable to the known strength or dimensions of any other given beam. If b be the breadth, d the depth, l the length, and w the breaking weight or ultimate strength of the given beam; let B the breadth, D the depth, L the length, W the breaking weight or strength of the required beam:

Then, as already mentioned, $\frac{b \times d^2}{l \times w} = \frac{B \times D^2}{L \times W}$ and $W = \frac{B \times D^2 \times l \times w}{b \times d^2 \times L}$ $B = \frac{b \times d^2 \times L \times W.}{D^2 \times l \times w}$ $D = \sqrt{\frac{b \times d^2 \times L \times W.}{B \times l \times w}}$ and L the length of the long beam $= l \times \sqrt{\frac{2w}{w}}$ adding the weight of the given beam. Now, by these equations, and the strength and

dimensions of any given beam, may be found the strength or dimensions of any other beam.

Example.—Required, the weight necessary to break a beam, when supported at the two ends and loaded in the middle, and whose dimensions are—length between the props, 8 feet 6 inches; breadth and depth $7\frac{1}{2}$ inches?—Taking the result of Buffon's experiments 1 and 2 as the data, we find that a beam 7 feet 6 inches long by $4\frac{1}{4}$ inches square, broke with a weight of 5716 lbs., which may be taken for the ultimate strength.

$$\text{Now } W = \frac{\overset{B}{7.5} \times \overset{D\,2}{7.5} = 421.8 \times \overset{l}{7.5} = 3163.5 \times \overset{w}{5716} = 18082566}{b \,\&\, d^2 = 4.2 \times 4.2^2 = 74 \times L = 8.5 \quad = \quad 629} = 28716.3 \text{ lbs. for the}$$

breaking weight or ultimate strength of the beam, as required.

To simplify the operation a little, the strength may be calculated from the known strength of a piece 1 foot long and 1 inch square, which is about 600 lbs. Then, in this case, b and d in the above $= 1$; also $l = 1$ foot and $w = 600$, and B, D, and L as before; $W = \dfrac{7.5 \times 7.5^2 \times 1 = 421.8 \times 600 = 253080}{1 \times 1^2 \times 8.5 \quad = \quad 8.5.} = 29321.5$ lbs; this giving the strength of the beam a little stronger than by the first data. But we find, by referring to Buffon's experiments, that an oak beam 8 feet 6 inches long, by $7\frac{1}{2}$ inches square, gave way with 28,033 lbs. exclusive of its own weight; by the first method the strength is found to be 28,716 lbs., which is very near that found by experiment; and had we taken into account the weight of the beams themselves, the difference would have been still less. It must now appear from this example, that small pieces of timber are proportionally stronger than large pieces, and consequently, that those experiments which have been made on the largest pieces of timber are by far the most valuable; in this respect, those of Buffon are worth all the others that have been made since.

Example 2d.—Given, the length and depth of the beam, also the load or weight; required, the breadth,—supposing the weight 29321.5 lbs. as before, length 8.5 feet, but to vary the question, the depth 10 inches?—then, by the second equation,—

$$B = \frac{1 \times 1^2 \times 8.5 \times 29321.5 = 269232.}{10 \times 10 = 100 \times l = 1 = 100 \quad w = 60000} = 4.4, \text{ the breadth of the beam, as required.}$$

Example 3d.—Again, and lastly, supposing we have the length, breadth, and weight given, as in the last example; required, the depth?—

$$D = \sqrt{} \; \frac{1 \times 1^2 \times 8.5 \times 29321.5 = 269232}{4{\cdot}4 \times 1 \times 600 \quad = \quad 2640} = 102 \text{ nearly, the square root of which is } 10 =$$

the depth of the beam as required.

Now, it must be observed, that by the above rule the strength of the beam is rather overrated, and consequently, although 1-4th of the weight required to break the beam may be laid on it, when proportioned according to the following rules by Mr. Barlow, yet not more than 1-5th of the greatest weight, as found by the above rules, should be laid on, as the strengths found by experiment do not come up to the computed strength; on the other hand, Mr. Barlow's rules are supposed to underrate the strength a little, which is certainly the safest for practice.

Mr. Peter Barlow has, after a very elaborate and patient investigation of the strength

and stress of timber, deduced some very valuable rules for its calculation, which, from their simplicity, may be easily retained on the memory for practical use; only, it will be necessary to have the following table of multiplicands for the different kinds of timber:—

English Oak,......1420	Beech,...............1556	Red Pine,............1342
Canadian do.......1766	Elm,.................1013	Fir,....................1100
Ash,................2026	Pitch Pine,.........1632	Larch,................1127

Then, with these, to find the ultimate transverse strength of a rectangular beam of any of the above kinds of timber, when fixed at one end and loaded at the other; multiply the number corresponding to the kind of wood by the breadth and square of the depth of the beam in inches, and divide the product by the length also in inches, and the quotient will be the weight in lbs. which will break the beam.

Example 1st.—What weight will be required to break a beam of oak, fixed at one end and loaded at the other, the breadth being 4 inches, depth 6 inches, and length 15 feet?—Suppose English oak—$1420 \times 36 = 51120$, and $\frac{51120 \times 4}{180} = 1136$ lbs. for the breaking weight. And the rule, when the beam is supported at both ends, is to multiply the number in the above table by the square of the depth in inches, and four times the breadth (because the beam supported at both ends, and loaded in the middle, is four times as strong as one of the same length and thickness in the first case); and divide that product by the length in inches, the quotient will be the weight or greatest strength of the beam in lbs.

Example 2d.—What weight will break a beam of English oak 9 inches in breadth, 10 inches deep, and 20 feet long, when supported at both ends and loaded in the middle? —$1420 \times 100 \times 36 = 5112000$, and $\frac{5112000}{240 \text{ in.}} = 21{,}300$ lbs., that is, about 9½ ton weight to break the beam; and when the beam is loaded equally throughout, the result must be doubled, for as it can subsequently be shewn, it will bear double the weight in this case, for it will only be strained the one half with the same weight. When the beam is firmly built into a wall, one-half of the above weight must be added for the breaking weight. Perhaps it might be doubled in this case, if it were possible to build the ends of the beam perfectly firm into the wall; for practice, however, only add half of what is required in the second case to itself, for the weight required in the third, because it is safest to err on this side. Mr. Barlow also gives a second rule for each of these three cases, in which the angle of deflection is considered; but this gives a higher result, and considering the many inequalities of timber, our calculations should not overrate its mean strength.

In our first demonstration of the mechanical action of the transverse strain, we considered the beam to turn on its upper edge in the act of breaking, when it is supported on props at both ends, or its lower edge, when it is fixed with one end into a wall, and loaded at the other, that is, the points R, (*Plate* IV. *Figs.* 68 and 69). But it appears evident that this is not strictly correct, when we consider the properties of timber, and the appearance of a fractured section of that material; for the fibres in the one part of

the section seem as if they had been torn in the direction of their length, while those of the other appear to be broke much shorter, and seem as if they had suffered compression. Independent of this appearance in favour of a new hypothesis, we have the very objections to Galileo's theory before mentioned; and we have also many mechanical illustrations which support an opinion, that the beam turns, when breaking, as it were on an axis, within the section of fracture; therefore when the beam is supported at both ends, and loaded in the middle, the lower fibres are suffering extension, while the upper ones are suffering compression—every fibre above this neutral axis being more and more compressed, as they are farther from the centre of motion, while every fibre below this point is suffering tension more and more as they are farther from the same. The point *n*, in Figs. 71, 73, 74, and remaining figures, represent this point: it is called the neutral axis; and it will appear evident, by inspecting the figures, that it will take to the lower or upper edge of the beam, according as it is either fixed at one end into a wall, and loaded at the other, or supported at the two ends, and loaded in the middle. *Fig.* 71 represents the fracture of a beam, broke close to the wall. It appears that the neutral point *n* (at which spot the fibres which coincide with the plane of *n* suffer neither extension nor compression) is about 3-8ths or 3-9ths from the lower edge in this case. *Fig.* 70 is a beam supported at both ends and loaded in the middle; T T′ are the points of support, *w* the weight, *n* the neutral axis; the fibres in *n s* are suffering compression, those in *n o* are suffering tension; the curve A S B is nearly a parabola.

Fig. 71, *Plate* IV. represents a beam built into a wall at the one end, and loaded with a weight *w* at the other; the beam is shewn as at the instant of breaking. The fundamental property of the curve which it assumes is, that the curvature at every part or point is as the distance of that point from the line of direction of the weight; and the curve thus produced is called by geometers, the elastic curve.

Fig. 72 is the representation of a beam solidly built into a wall at each end, and loaded in the middle; it is also shewn at the instant of fracture; *n* is the neutral point in the middle fracture; *n′* that at the end A, and *n″* that at the end B: for the beam in this case must not only be broke at the centre, but also at the edge of the wall at both ends.

Let us again consider the strain and resistance of beams fixed with one end into a wall, and loaded at the other, which if we know properly, every other case may be easily explained.

The force which causes the beam to bend or deflect from the straight line A B (*Fig.* 73, *Plate* IV.) is the weight W, suspended from the end C, multiplied into the length of the lever C *n*; and as the beam goes on to bend into the cosine of the angle *n* C H,* (I do not in this place consider the weight of the beam itself), the resistance which the beam opposes to the stress is, first, that of all the fibres in the section *n d*, which is the strength of one × the number × the distance of the centre of gravity of that section from the point *n*. It is also made up of the resistance of all the fibres in the section *n* F; to compression, which is the maximum force which the fibres present to compression, multiplied into the distance of the centre of gravity of the section *n* F from the point *n*. The strain on beams loaded with their own weight increases as the squares of their

* According to Barlow.

length. Let A B C D (*Fig.* 74, *Plate* IV.) be a beam projecting horizontally from a wall, loaded only with its own weight—suppose it to be homogeneous; now the strain by the weight of the first foot or division from D, as D 1, will be represented by the triangle D 1 e, the angle at 1 being a right angle, and the legs 1 D and 1 e are equal; likewise for the strain occasioned by another division 2, make $2f=$ to 2 D, then draw D ef; in like manner draw $3g$ and C E. Join E D; divide C E into the same number of equal parts as C D; through each of these, draw lines parallel to C D; also draw lines from the points 1 2 3, and parallel to D E; then will the strain at D, by every increase of the length of the beam, be represented by all the triangles between that division and point D; as by the second point out, the strain is increased equal to four triangles; by the third, the strain is increased to nine triangles, always increasing as the squares, $3\times3=9$; at the fourth and last division the effect is $4\times4=16$ triangles. Now the triangle D C E D will represent the whole strain on the beam AB by its own weight; this is the same as if it were loaded equally throughout the length, or had no weight of itself, but that a force of 4 were applied at the fourth division or extremity C. We have 16 triangles or half squares equal to 8 whole squares; now if we hang a weight W equal to 4 squares from the centre of gravity of the beam, (that is, at the second division), and multiply it by its distance from D; then the effect is equal also, for $4\times2=8$. Now, it can easily be proved, that the strain on a beam fixed with one end in a wall, and loaded with a weight at the other, is exactly equal to that on a beam of twice the length of the projecting part, supported on props at the two ends, and loaded with twice the weight.

By inspecting *Fig.* 74, *Plate* IV. it appears evident that the wall must press upon the end of the beam A L with a force equal to that on the projecting part A B, (this is expressed by the triangle D C E D), in order that it may hold the beam from canting up; therefore a fibre $n'n''$ will suffer an equal tension to a fibre so situated, if the end of the beam A L were as long as A B, and an equal weight hung at both ends, and D the fulcrum; see *Fig.* 75, where the end A F G D within the wall is equal to the part without. Now the strain on the fulcrum D, by the weight A B C D, is increased by the weight A F G D; D C E D contains 16 triangles or half squares; then when the beam is in equilibrio, by supposing the weight of A F G D multiplied into the distance of its centre of gravity from D, which is the same as multipling the 8 triangles or half squares, contained in the figure $abcd\times2$, for we would then have 16 half squares acting on the arm G D, in the same manner as the triangle represents the accumulated force on the other arm; it would then be expressed by the triangle D K G D. Now the strain on a beam projecting from a wall is equal to that on a beam of twice the length, when supported at the ends on props, and loaded with twice the weight, for the fibres $m'n'$ (*Fig.* 75) are extended equally to the fibres $m\,n$ (*Fig.* 76); for F B C G in this figure is a beam of double the length of A B, *Fig.* 74); it is supported at the ends on the props G and C; the strain at D A is equal to that at D A (*Fig.* 75); for it is also made up of two triangles D E G D and D E C D; these triangles also prove that this beam must break in the middle, where the greatest force is exerted. Suppose the prop C to be removed, and the end F G to be built solidly into a wall, then the strain on the beam F A B C D G (*Fig.* 76), is four times that on a beam of half the length, the triangle G C I G being four

times that of the triangle D C E D (*Fig.* 75). It is also four times that on a beam of the same length, when supported on props, from the cause already explained.

In all situations of beams, if when the load is collected at one end, when built solidly into a wall, or at the middle, when supported on props, it carries a certain weight; then, when the load is equally distributed throughout the whole length, the strain will be reduced one half, and it will then carry double the load, *et vice versa*.

The stiffness of beams, as before mentioned, is found to be directly as the breadth and cube of the depth, and inversely as the cube of the length. Hence, if we have a beam of double the length of another, and wish it to be equally stiff, we must make it twice as deep or eight times as broad; also, when a beam is projected out horizontally from a wall, the curvature produced by its own weight at every spot, is as the square of its distance from the extreme end.

The strength of a beam, when supported on props at each end, is to that of a beam of the same length projecting from a wall, in the ratio of 4 to 1; and the strength of a beam, when firmly built into a wall at each end, is to that of one of the same length between the props, when merely supported at the ends, as 4 to 2. Let A B and D E (*Fig.* 77, *Plate* IV.) be the section of two walls; let B D be the space between them; let the line A B C D E represent a beam built solidly into the walls at A B and D E. Now a beam in this position can be broken at the point C, by applying a weight sufficient for that purpose, but it cannot break at C, without breaking also at B and D. Let the triangles N and O represent the force necessary to break a beam of the length of B C and D C, projecting from a wall; now it will take twice any one of these triangles to break a beam of twice the length of B C or D C, when supported on props at both ends; we may therefore express this force by triangles Q and R (*Fig.* 77); these produce the fracture at C. The visible forces which break the beam at the points B C and D are represented in *Fig.* 78, by the four triangles N O Q R; but one half of the strain at B and D is produced by what may be called an invisible force; this is the weight of the succumbent wall, which keeps down the ends A B and D E; but we make it apparent by the triangles M and P, (*Fig.* 77). There are, therefore, six forces employed in producing the fractures at B C and D, which is exactly what we should expect, for by experiment I find that if the beam be placed upon props, as B and D, (*Fig.* 79), and loaded with the respective weights 1, 4, and 1, it will assume the form *a* BCD*e*; and when the strength and weights are in equilibrio by their position, it will, after it has attained the curvature, give way at the same instant at all the three parts B, C, and D.

But we must observe, that when the ends are built into a wall, as at A B and D E, the weight 4 in *Fig.* 79 must be nearly 5 before the fracture will take place. Some pieces gave way with 4½; it will therefore be the most proper estimate for practice.

For the beam supported on props, the strength will be the triangles Q + R.

For a beam of the same length between the wall into which its ends are fixed, the strength will be expressed by the triangles Q R + N O + half any of the triangles, as M, N, or P.

I have now shewn that the strain on beams, loaded equally throughout, or with their own weight, which is the same thing, increases as the squares of their lengths, and that when the load is collected at the end, or middle, that it increases rather faster

than in the simple ratio of the distance of the weight from the fulcrum; but some mathematicians give the strains in the three comparisons, when expressed correctly, to be—

1st, For a beam fixed at one end in a wall, and loaded at the other $l \times W \times \cos.^2 d$.
2d, When a beam of the same length is supported on props . $\frac{1}{4} l \times W \times \cos.^2 d$.
3d, When firmly fixed into a wall at each end . . . $\frac{1}{8} l \times W \times \cos.^2 d$.

In the formula, l is the length of the beam, W the weight with which it is loaded, $\cos.^2 d$ the square of the cosine of the angle of deflection; but it is little less than affectation for us to introduce this latter expression into the formula, because when our object is merely to proportion the dimensions of beams, &c. to the magnitude of the ship, or the load, which is seldom exactly known, so much accuracy would be a mere waste of time, therefore it will be sufficient to represent the strains for the above three cases simply thus:—For the *1st*, $l \times W = S$
" *2d*, $\frac{1}{4} l \times W = S$
" *3d*, $\frac{1}{8} l \times W = S$.

I am aware that some writers on the strength of timber give the strain in the third case, $\frac{1}{6} l \times W$, but I cannot find this to agree with experiment. The mode we have chosen of demonstration by the construction of the triangles is obvious, and will stand strict examination. The reader may therefore proceed, should his inclination incline, to consider many other propositions, by the principles we have laid down, for there are considerations respecting the strain on beams, curious and amusing in their nature, although not useful to the practical shipwright.

With respect to the comparative strength of beams of the same dimensions, but fixed with different angles of inclination to the horizon, the strengths will increase as the sines of elevation, and will be to a horizontal beam as the square of radius to the square of the cosine of elevation. If they are fixed by the one end into a wall, and placed the one with an inclination upwards and the other with the same angle of inclination downwards, and the length from the neutral axis to the point of suspension of the weight be the same in both, then the one which is inclined downwards is the weakest, for the horizontal distance of the line of direction of the weight from the fulcrum or neutral axis is greater than in the other case; but if the weight is sufficient to bend the beams from their first position, this distance will increase on the beam inclined upwards, and decrease on the other; this the reader may make manifest by a drawing of the beams. We mentioned before, that the curve which a beam assumes when bent under a load is called the elastic curve, and that its fundamental property is, that the curvature at every part is as the horizontal distance of that part from the line of direction of the weight; now the strain at every part is as the curvature at the same; the curvature next the wall on the beam inclined upwards is greater than on the same spot of the one inclined downwards; the strain on the former is therefore greater also. Therefore a beam placed with its inclination downwards, if loaded with such a weight as is sufficient to deflect it, is stronger than if it were placed with its inclination upwards; but this difference is small, and as the strain on the wall is much easier in the latter position than in the former, it will be best to place the beam with its end inclining upwards, and in this position it is much stronger than when projected out horizontally.

As to the strength of beams of different forms of the transverse section, we have only to consider such forms as are useful in practice; these are rectangular or prismatic. In rectangular beams, the lateral strength is as the breadth multiplied into the square of the depth, the depth being the principal dimension by which the strength is increased; if it is consistent with other connecting circumstances, it may be increased with advantage. The general proportion for joists is the breadth = 1-3d of the depth; but the material from which beams are cut will not allow of such a proportion; if the breadth be 2-3ds of the depth, the dimension is in a fair proportion, and the beam will be stiff both in a vertical and side direction. Mr. Emerson and some others have demonstrated, that a prismatic beam, with its angular point upwards, would be stronger after a part of its upper angular edge is taken off; this is in reference to its weight, of course, as augmenting the load. Experiment generally contradicts the assertion, that in such a case a part is stronger than the whole; there are, however, other cases, in which it naturally follows to be true.

Repulsive strength, or the power of bodies to resist compression.—The *third* distinct strain to which they are exposed, is much more difficult of investigation than any of the others, and the greatest analysts have been obliged to give way to the many difficulties which presented themselves at every step taken to enter into the minutiæ of the subject. The proportion of the repulsive force arising from the cohesion of the particles, or the force of these particles, is not exactly known, and perhaps never will be known; but experience teaches us, that there is a certain relation between the weight of bodies and the force of the particles of which they are composed, or rather of the matter of which the particles consist, which even nature herself cannot do away; this puts a limit to the magnitude of the productions both of nature and art.

Philosophers have endeavoured to trace the laws of repulsion, and to calculate the altitude necessary to compress the material of a column at the bottom, so that the lower parts would be crushed and crumble down, and of course the whole fabric tumble to the ground. The most precise experiments, however, which have been made, to ascertain the repulsive force of different materials, were made by Mr. George Rennie in 1817.

It is necessary, in most mechanical erections, to know the repulsive force of different materials—to know, for example, what weight a pillar of wood will support on its upper end before breaking or bending. It could not bend, but be crushed, under the load, if were possible to apply it fairly; but the moment a bend begins, the strain increases, and becomes oblique. The repulsive force depends upon the structure of the body. If the fibres lie in right lines from end to end, it will be much stronger than if they were winded or bent. Thus oak, although a stronger wood than fir, will not bear so much when employed as a pillar; also cast iron resists compression with a force equal to twice its cohesion. Freestone is said to support about 8000 lbs. per square inch; and good oak about 3000 lbs. per square inch. But it must be observed, that the strength of different materials, to resist compression, is liable to great irregularities. In some materials, the cohesive and repulsive strength is nearly equal; while in others, the one exceeds or falls short of the other in double and triplicate ratios, according to

the nature of the material. For example, freestone will only suspend about 857 lbs. per square inch; but it will support, according to Mr. Rennie's experiments, 8688 lbs. Also, English elm will suspend about 9000 lbs. per square inch, while at the same time it will not support more than 1000 lbs.; and so on for other substances, according to their particular nature.

Although it might appear that the length of the columns to be crushed should not affect the operation farther than by the increase of their weight, yet it is affirmed that it actually does; and that when the length of the column exceeds 30 or 40 times its base, the resistance to compression is much diminished.

There is one law which these opposite forces seem to follow, at least for small weights, viz. that the measure of extension and compression of uniform elastic bodies is simply proportional to the force which occasions it. This law was discovered by Dr. Hook. For example, if the weight of 100 lbs. lengthened a rod of metal the 100th part of an inch, a weight of 200 lbs. would lengthen it 200 parts of an inch, and so on; also, the same weights acting in the opposite direction, would compress or shorten it in the same proportion. But here we must notice, that the longitudinal distension or compression of the body does not follow the above law; but while the weights or forces applied are less than about half as much as will be necessary to tear the body asunder, for if the weights employed be greater than this, the extension of the body will be doubled by every addition of weight of about 1-8th part of the disruptive force,* that is, of the force necessary to tear it asunder. And it may be inferred from the above, and also other causes, that the repulsive force of the material increases as the weights are laid on, in the same manner that the cohesive force diminishes as the weights suspended to tear them asunder. Therefore the compressions of the material will not be in the simple ratio of the weights applied. The height or weight of a column, of the material which would be sufficient to compress it into half its original dimensions, is called the modulus of the elasticity of that material; and it may either be stated in weight or feet. Thus the modulus of the elasticity of a square inch of steel is 3,000,000 lbs. = to a column of that material of 1 inch square in the section, and 750,000 feet in height. But it is supposed that the extension is proportional to the weights applied; hence if we know the cohesive force of the metal, and what proportion it bears to the modulus elasticity, we know its utmost extension before giving way.

On the Wrenching or Twisting Strain.

To understand properly the nature of this strain, is perhaps more particularly important to the mill-wright than the ship-carpenter. It is under this force or strain that those shafts, which communicate motion from one part of a machine to another, give way.

First when steam-boats were set a-going, they very often broke their paddle shafts, which had probably been only calculated to resist a wrenching force equal to that exerted by land engines of a corresponding power. But experience has now shewn that the machinery employed in propelling vessels must be proportionally stronger, particularly the connecting rods, arbors, journals, shafts, &c. than for an engine of equal

* Leslie's Elements of Natural Philosophy, p. 215.

power to be employed on land, because the engines of steam-vessels are exposed to tugging, and very unequal strains.

It frequently happened that the paddle shafts gave way when the boat was heeled over to one side, when the lee paddle is deeply immersed, and the weather one having little or no hold of the water, which occasions a much more severe strain on the shaft than if both paddles are equally immersed, which diffuse the strain fairly throughout the whole shaft. Steam-vessels are generally fitted with two engines, in order that the cranks, which are placed at right angles to each other, may turn the centre without the assistance of a fly wheel, which is considered an unnecessary appendage to a steam-boat's engine. When the vessel is upright, both paddles being fairly immersed, the strain on the main shaft is produced by the power of the engine and the resistance of the water to the floats; and the same takes place by the other engine and paddles on the opposite side of the ship, so that the wrenching strain on each half of the shaft is occasioned by the power of one of the engines. But observe, that when the boat is heeled over to one side, the lee paddle becomes doubly immersed, while the other is raised almost free from the water. Now the lee one, being doubly resisted and acted upon by the force of the two engines, it is natural to expect that if the shaft is not sufficiently strong, it must give way at that side, which is commonly found to be the case. The head of the rudder or rudder-stock is exposed to very powerful wrenching strains, by means of the tiller, which is fixed into it for the purpose of steering the vessel. The barrel of the capstan is exposed to the same strain; also when a rope is taken round the end of the windlass, the spindle is exposed to a very powerful wrenching strain. If it is required to heave a great strain or force by means of the windlass, the rope should not be taken round the windlass end, as is sometimes the case, but round the body of the windlass. If a heavy body is to be raised by the winch, the power should be exerted at both ends of the spindle, or at least the rope should not be wound round the opposite end of the winch, to which the power to heave it round is applied. If one handle only can be wrought, the rope should, if possible, be taken round the same end of the winch, as the wrenching strain is proportional to the length of the spindle, and the power of the spindle inversely proportional to the same, and as the cube of the diameter: some take it as the 4th power of the diameter; but engineers make the strength as the cube and number of revolutions in a given time. It is evident that the quantity of material is as the cube of the diameter of the shaft or spindle; and as the mechanical action of this strain has not yet been properly ascertained for the different kinds of material, some of which, as timber, can hardly be considered any other than a bundle of fibres adhering laterally together—others, such as iron, &c. as an infinite number of small particles equally diffused throughout the body, in all practical cases the strength is commonly taken as the cube of the diameter of the shafts respectively. Thus if a shaft of D number of inches in diameter resist a wrenching force of 6 tons, then another of the same length, but 2 D in diameter, will resist $D^3 = 8 : 6 :: 64 : 48$ tons; the diameter D being $= 2$.

Again, if a shaft of 4 inches resist a wrenching force of 48, what force will one of 2 inches, making the same number of revolutions, resist?—Then $64 : 48 :: 8 : 6$ tons.

It is said that a cast-iron shaft is stronger when subjected to a torsional strain, than a malleable iron rod of the same diameter; and when the strength of malleable iron is less than cast iron to resist tension, it is stronger than cast iron to resist lateral pressure, in the proportion, the former to the latter, of 14 to 9.

If the diameter of a cast-iron journal is 8 inches, and it is required to find the diameter of a malleable iron journal to bear equal weight?—Then $8^3 = 512$, and $14 : 512 :: 9 : 329.1$, and $\sqrt[3]{329} = 6\frac{7}{8}$, or nearly 7 inches.

The strength of direct cohesion of a square inch of iron is rather more than three times that of the strongest kind of wood,—the strength of direct cohesion of box being 20,000 lbs., while that of common iron is 60,280 lbs., nearly in the ratio of 6 to 2. The comparative strength of oak with iron is as 1 to 6, or the latter to the former as 6 to 1. The proportional strength of a square inch of iron, oak, and best common rope, stands thus:—iron, 6; oak, 1; rope, .75.

Experiments made by Thomas Telford, Esq. upon the direct strength of cohesion of malleable iron, furnish the ultimate strength of a bar of iron, one inch square; also by Captain S. Brown, inventor of the chain cable:—

From Captain S. Brown's Experiments.

	A Bar, one inch square, of	*Torn asunder by*		*A Bar, one inch square, of*	*Torn asunder by*
1.	Swedish Iron,	Tons, 23.77	7.	Welch Iron,	Tons, 26.33
2.	Ditto,	23.19	8.	Blistered Steel,	14.27
3.	Ditto,	23.75	9.	Cast Steel,	27.92
4.	Russia,	26.55	10.	Cast Iron Welch Pig,	7.26
5.	Welch,	24.35	11.	Welch,	26.34
6.	Ditto,	24.90			

Mean of the first 7 and the 11th, 25 tons.

From Mr. Telford's Experiments.

		Tons.	Cwt.			Tons.	Cwt.
1.	Welch Iron,	29	6	6.	Swedish Iron,	29	0
2.	Ditto,	29	16	7.	Fagotted,	29	0
3.	Staffordshire,	27	3	8.	Staffordshire,	31	0
4.	Ditto,	27	10	9.	Ditto,	31	16
5.	Welsh,	29	0			9)263	11
					Mean of the whole .	29	5⅔

Mean strength, according to Captain Brown, . 25 tons.
Ditto ditto Mr. Telford, . . $29\frac{1}{4}$ tons.

2)54

Mean of the two . 27 tons, which may be safely taken for the medium strength of an iron bar 1 inch square.

The strength of a bolt made in the form of the link of a chain-cable, is found to be about $21\frac{1}{2}$ tons; while, by the same machine, the main strength of the same iron is

25 tons. When stays are introduced between the links, the strength of the iron is nearly equal to what it is in the simple bar form, so that the stay is said to increase the strength of the chain about 1-6th; but at the same time they also increase the weight, which again tends to diminish the strength of the chain.

The experiments of Mr. George Rennie, in 1817, furnish the cohesive strength of a rod one inch square of different metals in pounds avoirdupois, with the corresponding length in feet of the metal, which would cause it to be torn asunder if hung in a vertical position:—

	Lbs.	Feet.		Lbs.	Feet.
Cast Steel,..................	134,256	39,455	Cast Copper,................	19,072	5,003
Swedish malleable Iron,..	72,064	19,740	Yellow Brass,...............	17,958	5,000
English ditto ditto,.......	55,872	16,930	Cast Tin,.....................	4,736	1,496
Cast Iron,....................	19,096	6,110	Ditto Lead,..................	1,824	348

The strength of the Swedish malleable iron is 32 tons, which exceeds the strength of the same metal as given by Captain Brown and Mr. Telford; but the English malleable iron nearly agrees with the strength as found by the former. The cohesion of hempen fibres is generally estimated at 6400 lbs. for every square inch of the transverse section; but the constituent ropes of a cable are stronger, when separate, than the cable, as 4 to 3; and a rope, when worked up from yarns 180 yards in length to 135, is found to be stronger than when reduced to 120 yards, in nearly the ratio of 6 to 5. Mr. Huddart's ropes of 100 yarns are only supposed to lose 1-8th or 1-9th of the ultimate strength of the yarns. If the square of the girth in inches is divided by 4, the quotient will be nearly the ultimate strength of the rope in tons, so that if the girth is 5 inches, its utmost strength is $5 \times 5 = 25 \div 4 = 6$ tons. The utmost strength of ropes of the following girth has been found by experiment:—

A rope of 4 inches in circumference broke with 4 tons.
Ditto $3\frac{1}{2}$ - - - - - - - 3 „
Ditto 3 - - - - - - - 2 „ 15 cwt.

In general, 1-5th of the square of the circumference in inches may be considered the ultimate strength of ropes.

In a subsequent part of this work will be found practical rules for calculating the weight and comparative strength of ropes; also the rules for proportioning the standing rigging according to the different sizes of vessels.

As a substitute for the operation of extracting the Square and Cube Roots, which is much required in mechanical calculations, particularly in finding the comparative strength of materials, I have calculated the square and cube of every inch and 1-8th part, from 1 inch to 32, rising gradually by 1-8th, and arranged the result into the following Table, from which may be taken the square or cube roots of the numbers herein given; that is, the cube root of almost any number below 32,768., or the square root of any number below 1024., which roots are expressed in inches and 1-8th parts. For example, suppose the momentum of any square beam is 401.130 inches, and it is required to find the side of the square,—look for the number 401.130 in the column marked Cubes, over against which, in the column marked Roots, will be found $7\frac{3}{8}$, which is the side of the beam in inches and 1-8th parts.

A TABLE *of* SQUARES *and* CUBES, *with their Roots, calculated to every one-eight part, from one to thirty-two inches.*

Roots.	Squares.	Cubes.	Roots.	Squares.	Cubes.	Roots.	Squares.	Cubes.
1	1.000	1.000	7	49.000	343.000	13	169.000	2197.000
1½ ⅛	1.265	1.423	1½ ⅛	50.765	361.605	1½ ⅛	172.265	2260.986
3 ¼	1.562	1.953	3 ¼	52.562	381.078	3 ¼	175.562	2326.303
4½ ⅜	1.890	2.609	4½ ⅜	54.390	401.130	4½ ⅜	178.890	2392.662
6 ½	2.250	3.375	6 ½	56.250	421.875	6 ½	182.250	2460.375
7½ ⅝	2.640	4.291	7½ ⅝	58.140	443.322	7½ ⅝	185.604	2529.353
9 ¾	3.062	5.359	9 ¾	60.062	465.484	9 ¾	189.062	2599.609
10½ ⅞	3.515	6.591	10½ ⅞	62.015	488.373	10½ ⅞	192.515	2671.155
2	4.000	8.000	8	64.000	512.000	14	196.000	2744.000
1½ ⅛	4.515	9.595	1½ ⅛	66.015	536.376	1½ ⅛	199.515	2818.158
3 ¼	5.062	11.309	3 ¼	68.062	561.515	3 ¼	203.062	2893.640
4½ ⅜	5.641	13.398	4½ ⅜	70.140	587.427	4½ ⅜	206.640	2970.458
6 ½	6.250	15.625	6 ½	72.250	614.125	6 ½	210.250	3048.625
7½ ⅝	6.890	18.087	7½ ⅝	74.390	641.619	7½ ⅝	213.890	3128.150
9 ¾	7.552	20.769	9 ¾	76.562	669.921	9 ¾	217.562	3209.046
10½ ⅞	8.265	23.763	10½ ⅞	78.765	699.044	10½ ⅞	221.265	3291.326
3	9.000	27.000	9	81.000	729.000	15	225.000	3375.000
1½ ⅛	9.765	30.517	1½ ⅛	83.265	759.798	1½ ⅛	228.765	3460.080
3 ¼	10.562	34.328	3 ¼	85.562	791.453	3 ¼	232.562	3546.578
4½ ⅜	11.390	38.443	4½ ⅜	87.891	823.883	4½ ⅜	236.390	3634.505
6 ½	12.250	42.875	6 ½	90.250	857.375	6 ½	240.250	3723.875
7½ ⅝	13.140	47.634	7½ ⅝	92.640	891.666	7½ ⅝	244.140	3814.697
9 ¾	14.062	52.734	9 ¾	95.062	926.859	9 ¾	248.062	3906.984
10½ ⅞	15.016	58.189	10½ ⅞	97.515	962.966	10½ ⅞	252.015	4000.784
4	16.000	64.000	10	100.000	1000.000	16	256.000	4096.000
1½ ⅛	17.015	70.189	1½ ⅛	102.515	1037.970	1½ ⅛	260.015	4192.751
3 ¼	18.062	76.765	3 ¼	105.062	1076.890	3 ¼	264.062	4291.015
4½ ⅜	19.140	83.742	4½ ⅜	107.640	1116.771	4½ ⅜	268.140	4390.802
6 ½	20.250	91.125	6 ½	110.250	1157.625	6 ½	272.250	4492.125
7½ ⅝	21.390	98.931	7½ ⅝	112.890	1199.462	7½ ⅝	276.390	4594.994
9 ¾	22.562	107.171	9 ¾	115.562	1242.296	9 ¾	280.552	4699.254
10½ ⅞	23.765	115.857	10½ ⅞	118.265	1286.138	10½ ⅞	284.765	4805.319
5	25.000	125.000	11	121.000	1331.000	17	289.000	4913.000
1½ ⅛	26.265	134.611	1½ ⅛	123.765	1376.892	1½ ⅛	293.265	5022.173
3 ¼	27.562	144.703	3 ¼	126.562	1423.802	3 ¼	297.562	5132.953
4½ ⅜	28.890	115.287	4½ ⅜	129.390	1471.818	4½ ⅜	301.890	5245.849
6 ½	30.250	166.375	6 ½	132.250	1520.875	6 ½	306.250	5359.375
7½ ⅝	31.640	177.978	7½ ⅝	135.140	1571.009	7½ ⅝	310.640	5475.041
9 ¾	33.062	190.109	9 ¾	138.062	1622.234	9 ¾	315.062	5592.359
10½ ⅞	34.515	202.779	10½ ⅞	141.015	1674.560	10½ ⅞	319.515	5711.341
6	36.000	216.000	12	144.000	1728.000	18	324.000	5832.000
1½ ⅛	37.515	229.783	1½ ⅛	147.005	1782.441	1½ ⅛	328.515	5954.355
3 ¼	39.06[illegible]	244.140	3 ¼	150.062	1838.265	3 ¼	333.062	6078.390
4½ ⅜	40.640	259.083	4½ ⅜	153.140	1895.115	4½ ⅜	337.640	6204.146
6 ½	42.250	274.625	6 ½	156.250	1953.125	6 ½	342.250	6331.625
7½ ⅝	43.890	290.775	7½ ⅝	159.390	2012.306	7½ ⅝	346.890	6460.837
9 ¾	45.552	307.479	9 ¾	162.562	2072.671	9 ¾	351.526	6591.796
10½ ⅞	47.265	324.951	10½ ⅞	165.765	2134.232	10½ ⅞	356.265	6724.513

Table of Squares and Cubes—(continued.)

Roots.	Squares.	Cubes.	Roots.	Squares.	Cubes.	Roots.	Squares.	Cubes.
19	361.000	6859.000	24	576.000	13824.000	29	841.000	24389.000
1½ ⅛	365.765	6995.267	1½ ⅛	582.015	14041.126	1½ ⅛	848.265	24705.736
3 ¼	370.526	7133.328	3 ¼	588.062	14260.515	3 ¼	855.562	25025.203
4½ ⅜	375.390	7273.193	4½ ⅜	594.140	14482.177	4½ ⅜	862.890	25347.412
6 ½	380.250	7414.875	6 ½	600.250	14706.125	6 ½	870.250	25672.375
7½ ⅝	385.140	7558.384	7½ ⅝	606.390	14932.369	7½ ⅝	877.640	26000.103
9 ¾	390.062	7703.734	9 ¾	612.562	15160.921	9 ¾	885.062	26330.609
10½ ⅞	395.015	7850.935	10½ ⅞	618.765	15391.792	10½ ⅞	892.515	26663.904
20	400.000	8000.000	25	625.000	15625.000	30	900.000	27000.000
1½ ⅛	405.017	8150.979	1½ ⅛	631.625	15860.548	1½ ⅛	907.515	27338.908
3 ¼	410.062	8303.765	3 ¼	637.562	16098.453	3 ¼	915.062	27680.640
4½ ⅜	415.140	8458.490	4½ ⅜	643.890	16338.724	4½ ⅜	922.640	28025.107
6 ½	420.250	8615.125	6 ½	650.640	16581.375	6 ½	930.250	28372.625
7½ ⅝	425.390	8773.681	7½ ⅝	656.646	16826.416	7½ ⅝	937.890	28722.900
9 ¾	430.562	8934.171	9 ¾	663.062	17073.859	9 ¾	945.562	29076.046
10½ ⅞	435.765	9096.607	10½ ⅞	669.514	17323.690	10½ ⅞	953.265	29432.076
21	441.000	9261.000	26	676.000	17576.000	31	961.000	29791.000
1½ ⅛	446.265	9427.361	1½ ⅛	682.515	17323.716	1½ ⅛	968.765	30512.830
3 ¼	451.562	9595.703	3 ¼	689.062	18088.890	3 ¼	976.562	30517.578
4½ ⅜	456.890	9766.037	4½ ⅜	695.640	18347.521	4½ ⅜	984.390	30885.255
6 ½	462.250	9938.375	6 ½	702.250	18609.625	6 ½	992.250	31255.875
7½ ⅝	467.640	10112.728	7½ ⅝	708.890	18874.202	7½ ⅝	1000.130	31629.131
9 ¾	473.062	10289.109	9 ¾	715.562	19141.296	9 ¾	1008.062	32005.984
10½ ⅞	478.515	10467.517	10½ ⅞	722.265	19410.878	10½ ⅞	1016.015	32385.498
22	484.000	10648.000	27	729.000	19683.000	32	1024.000	32768.000
1½ ⅛	489.515	10830.533	1½ ⅛	735.765	19957.642			
3 ¼	495.062	11015.040	3 ¼	742.562	20234.828			
4½ ⅜	500.640	11201.831	4½ ⅜	749.390	20514.568			
6 ½	506.250	11390.625	6 ½	756.250	20796.875			
7½ ⅝	511.890	11581.515	7½ ⅝	763.140	21081.759			
9 ¾	517.562	11774.546	9 ¾	770.062	21369.234			
10½ ⅞	523.265	11969.701	10½ ⅞	777.015	21659.310			
23	529.000	12167.000	28	784.000	21952.000			
1½ ⅛	534.765	12366.455	1½ ⅛	791.015	22247.314			
3 ¼	540.562	12568.078	3 ¼	798.062	22545.265			
4½ ⅜	546.390	12771.880	4½ ⅜	805.140	22845.865			
6 ½	552.250	12977.875	6 ½	812.250	23148.125			
7½ ⅝	558.140	13186.072	7½ ⅝	819.390	23455.056			
9 ¾	564.052	13396.246	9 ¾	826.562	23763.671			
10½ ⅞	570.015	13609.123	10½ ⅞	833.765	24074.982			

The above Table will be extremely useful to shipwrights, millwrights, or engineers, shipmasters, and others, when comparing the strength of beams or iron shafts, journals, ropes, &c. all materials subjected to transverse strains—the cube of the diameter being taken; and for iron rods, ropes, &c. that are subjected to longitudinal strains, such as connecting and piston rods, their strength is as the squares of the diameter. It was from experiencing the want of some such table, when comparing the strength of masts, ropes, &c. that first led me to compute the above, none of the common tables of squares and cubes which I have ever seen being so well adapted for this purpose. The above table is calculated to inches and eighth parts, from 1 to 32 inches, and it may either be taken as eighth parts, inches and eighth parts, or as feet and inches. Thus, when it is

required to find the squares or cubes in eighth parts only, take the figures opposite the whole numbers, as 2, 3, 4, 5, 6, &c.; and then, taking the intermediate parts marked $\frac{1}{8}$, &c. will divide those eighth parts into other eighth parts, so that the squares or their roots may be found to the 64th part of an inch, or the eighth part of one-eighth of an inch. Thus, the square root 7.552 eight parts is two eighth parts, and 3-4ths of one eighth part is also the cube root 20.769 eight parts. When the whole numbers are taken as inches, the intermediate lines are the eighth parts of the inches, as regularly marked. Again, when the whole numbers are taken as feet, the intermediate lines are the eighth parts of a foot; so that the roots increase by one and one-half inches, as the figures $1\frac{1}{2}$, 3, $4\frac{1}{2}$, 6, $7\frac{1}{2}$, 9, $10\frac{1}{2}$, placed in the left side of the column of roots.

Example.—The cube root of 5475.041 feet = 17 feet $7\frac{1}{2}$ inches.

The square root of 310.640 feet = 17 feet $7\frac{1}{2}$ inches.

TABLE of the Comparative Strength of Beams of different Dimensions; also shewing the Size of the Paddle-Beams for Steam-Boats at the Gunwale, from those required for a small Boat with a 5-Horse Power Engine up to those required for a Boat with Engines of 260-horse Power.

No. of Horse-Power of the Engines.	Momentum, or the Square of the Depth × the Breadth.	Dimensions of the Sides for Square Beams.	Dimensions of unequal-sided Beams, the Breadth 2-3ds the Depth.	Dimensions of unequal-sided Beams, the Breadth half the Depth.	Dimensions of unequal-sided Beams, the Breadth 1-3d the Depth.	Dimensions of unequal-sided Beams, the Breadth 1-4th the Depth.
		Inches.	Inches. Inches.	Inches. Inches.	Inches. Inches.	Inches. Inches.
5	366	$7\frac{1}{8}$	$8\frac{3}{16}$ by $5\frac{1}{2}$	9 by $4\frac{1}{2}$	$10\frac{1}{4}$ by $3\frac{3}{8}$	$11\frac{3}{8}$ by $2\frac{7}{8}$
10	476	$7\frac{3}{4}$	$8\frac{7}{8}$,, $5\frac{7}{8}$	10 ,, $4\frac{3}{4}$	$11\frac{1}{4}$,, $3\frac{3}{4}$	$12\frac{3}{8}$,, $3\frac{1}{8}$
15	586	$8\frac{3}{8}$	$9\frac{1}{2}$,, $6\frac{3}{8}$	$10\frac{5}{8}$,, $5\frac{1}{4}$	$12\frac{1}{8}$,, 4	$13\frac{1}{4}$,, $3\frac{5}{16}$
20	696	$8\frac{7}{8}$	$10\frac{1}{8}$,, $6\frac{3}{4}$	$11\frac{1}{8}$,, $5\frac{1}{2}$	$12\frac{3}{4}$,, $4\frac{1}{4}$	14 ,, $3\frac{1}{2}$
25	806	$9\frac{3}{8}$	$10\frac{5}{8}$,, $7\frac{1}{8}$	$11\frac{3}{4}$,, $5\frac{7}{8}$	$13\frac{3}{8}$,, $4\frac{1}{2}$	$14\frac{3}{4}$,, $3\frac{5}{8}$
30	916	$9\frac{3}{4}$	$11\frac{1}{8}$,, $7\frac{3}{8}$	$12\frac{1}{4}$,, $6\frac{1}{8}$	14 ,, $4\frac{5}{8}$	$15\frac{5}{8}$,, $3\frac{7}{8}$
35	1026	$10\frac{1}{8}$	$11\frac{1}{2}$,, $7\frac{5}{8}$	$12\frac{3}{4}$,, $6\frac{3}{8}$	$14\frac{1}{2}$,, $4\frac{7}{8}$	16 ,, 4
40	1136	$10\frac{1}{2}$	12 ,, 8	$13\frac{1}{8}$,, $6\frac{1}{2}$	15 ,, 5	$16\frac{1}{2}$,, $4\frac{1}{8}$
45	1246	$10\frac{3}{4}$	$12\frac{1}{4}$,, $8\frac{1}{4}$	$13\frac{1}{2}$,, $6\frac{3}{4}$	$15\frac{1}{2}$,, $5\frac{3}{16}$	17 ,, $4\frac{1}{4}$
50	1356	$11\frac{1}{8}$	$12\frac{5}{8}$,, $8\frac{1}{2}$	$13\frac{7}{8}$,, $6\frac{7}{8}$	16 ,, $5\frac{3}{8}$	$17\frac{1}{2}$,, $4\frac{3}{8}$
55	1466	$11\frac{3}{8}$	13 ,, $8\frac{5}{8}$	$14\frac{1}{4}$,, $7\frac{1}{8}$	$16\frac{3}{8}$,, $5\frac{1}{2}$	18 ,, $4\frac{1}{2}$
60	1576	$11\frac{5}{8}$	$13\frac{1}{4}$,, $8\frac{7}{8}$	$14\frac{5}{8}$,, $7\frac{3}{8}$	$16\frac{3}{4}$,, $5\frac{1}{2}$	$18\frac{1}{2}$,, $4\frac{5}{8}$
65	1686	$11\frac{7}{8}$	$13\frac{5}{8}$,, $9\frac{1}{8}$	15 ,, $7\frac{1}{2}$	$17\frac{1}{8}$,, $5\frac{3}{4}$	$18\frac{7}{8}$,, $4\frac{3}{4}$
70	1796	$12\frac{1}{8}$	$13\frac{7}{8}$,, $9\frac{1}{4}$	$15\frac{3}{8}$,, $7\frac{5}{8}$	$17\frac{1}{2}$,, $5\frac{7}{8}$	$19\frac{1}{4}$,, $4\frac{7}{8}$
75	1906	$12\frac{3}{8}$	$14\frac{3}{16}$,, $9\frac{1}{2}$	$15\frac{3}{4}$,, $7\frac{3}{4}$	$17\frac{7}{8}$,, 6	$19\frac{5}{8}$,, $4\frac{15}{16}$
80	2016	$12\frac{5}{8}$	$14\frac{1}{2}$,, $9\frac{5}{8}$	16 ,, 8	$18\frac{1}{4}$,, $6\frac{1}{8}$	20.5 ,, 5.1
85	2126	$12\frac{7}{8}$	$14\frac{3}{4}$,, $9\frac{7}{8}$	$16\frac{1}{4}$,, $8\frac{1}{8}$	$18\frac{1}{2}$,, $6\frac{3}{16}$	
90	2236	$13\frac{1}{8}$	15 ,, 10	$16\frac{1}{2}$,, $8\frac{1}{4}$	$18\frac{7}{8}$,, $6\frac{1}{4}$	
95	2346	$13\frac{5}{16}$	$15\frac{1}{4}$,, $10\frac{1}{8}$	$16\frac{3}{4}$,, $8\frac{3}{8}$	$19\frac{1}{8}$,, $6\frac{3}{8}$	
100	2456	$13\frac{1}{2}$	$15\frac{1}{2}$,, $10\frac{1}{4}$	17 ,, $8\frac{1}{2}$	$19\frac{1}{2}$,, $6\frac{1}{2}$	
105	2566	$13\frac{5}{8}$	$15\frac{5}{8}$,, $10\frac{1}{2}$	$17\frac{1}{4}$,, $8\frac{5}{8}$	$19\frac{3}{4}$,, $6\frac{5}{8}$	
110	2676	$13\frac{7}{8}$	$15\frac{7}{8}$,, $10\frac{5}{8}$	$17\frac{1}{2}$,, $8\frac{3}{4}$	20 ,, $6\frac{5}{8}$	
115	2786	$14\frac{1}{16}$	$16\frac{1}{8}$,, $10\frac{3}{4}$	$17\frac{3}{4}$,, $8\frac{7}{8}$	$20\frac{1}{4}$,, $6\frac{3}{4}$	
120	2896	$14\frac{1}{4}$	$16\frac{1}{4}$,, $10\frac{7}{8}$	18 ,, 9	$20\frac{1}{2}$,, $6\frac{7}{8}$	
125	3006	$14\frac{1}{2}$	$16\frac{1}{2}$,, 11	$18\frac{1}{4}$,, $9\frac{1}{8}$	$20\frac{7}{8}$,, 7	
130	3116	$14\frac{5}{8}$	$16\frac{3}{4}$,, $11\frac{1}{8}$	$18\frac{3}{8}$,, $9\frac{3}{16}$	$21\frac{1}{8}$,, $7\frac{1}{32}$	
140	3336	15	$17\frac{1}{8}$,, $11\frac{1}{4}$	$18\frac{3}{4}$,, $9\frac{3}{8}$	$21\frac{5}{8}$,, $7\frac{1}{4}$	
150	3556	$15\frac{1}{4}$	$17\frac{1}{2}$,, $11\frac{5}{8}$	$19\frac{1}{4}$,, $9\frac{5}{8}$		
160	3776	$15\frac{5}{8}$	$17\frac{7}{8}$,, $11\frac{7}{8}$	$16\frac{5}{8}$,, $9\frac{7}{8}$		
170	3996	$15\frac{7}{8}$	$18\frac{1}{8}$,, 12	20 ,, 10.		
180	4116	$16\frac{1}{8}$	$18\frac{3}{8}$,, $12\frac{1}{8}$	$20\frac{1}{4}$,, $10\frac{1}{8}$		
190	4336	$16\frac{3}{8}$	$18\frac{5}{8}$,, $12\frac{3}{16}$			
200	4556	$16\frac{5}{8}$	19 ,, $12\frac{3}{8}$			
220	4996	$17\frac{1}{8}$	$19\frac{1}{2}$,, 13			
240	5436	$17\frac{5}{8}$				
260	5876	18				

Note.—Each of the above columns of dimensions is carried as far as the largest size of timber. For the method of calculating the Table, see rules for the comparative strength of beams, p. 46, problem 2.

CHAPTER IV.

HYDROSTATICS AND HYDRAULICS.

Hydrodynamics is the science which applies the principles of Dynamics, to determine the conditions of motion and rest in fluid bodies. It is divided into four parts:—*1st, Hydrostatics,* which explains the laws of equilibrium and pressure of fluids, which are supposed incompressible, such as water; *2d, Hydraulics,* which explains the laws of the motions of incompressible fluids; *3d, Aerostatics,* which treats of the laws and equilibrium of elastic fluids, such as air; *4th, Pneumatics,* which treats of the motion of elastic fluids.

Although the whole science of Hydrodynamics is in a greater or lesser degree connected with the theory of Marine Architecture, it will be sufficient for our purpose to be acquainted with the two first divisions of that science, Hydrostatics and Hydraulics, which explain the laws of that fluid in which the ship is intended to act. If we are unacquainted with the nature and action of water, we shall in all probability construct the vessel on false principles, which will be easily discovered by her performance at sea. All the knowledge we can acquire respecting the action of fluids is indispensably necessary; and it not unfrequently happens, that with all our information we do not succeed so completely as we could wish.

I propose, in the first place, to offer a few observations on the properties of Water, such as the cause of its fluidity, &c.

It is well known, that in common circumstances water cannot exist as a fluid under a lower temperature than about 28 or 30 degrees of Fahrenheit's thermometer, for it is then changed into a transparent and solid substance called ice. Water is not considered a pure element, but fire is. Water contains fire, which is said to be the chief cause of its fluidity. Every one is aware, that when fire is diffused through water, its fluidity is increased. Water is a compound of two elements, oxygen and hydrogen gas, or pure and inflammable air; these can be decomposed into water. The heat of the flame produced by burning together certain portions of these gases is the most intense which has as yet been discovered. By heating to a certain degree a piece of ice, we obtain a fluid of the same degree of temperature as the ice itself. Steam or vapour is obtained from water in like manner, by raising the temperature of the water: it is a finer and more pliable fluid than water; therefore it is easier to move a body through this medium than through water.

Water is supposed to consist of an infinite number of very small particles, which do not touch each other. The distance between them is infinitely small; and as it expands in heating, and contracts in cooling down to about 30 degrees, it is inferred, that when this expanding and contracting takes place, the particles are separated, and again drawn together. When water is heated, there is a quantity of fire, or as it is

called in chemical phraseology, caloric, forced between the particles, which separates them, whereby the same number fill a greater space. The same remark applies to all bodies which are subject to visible expansions and contractions. But the cause of the fluidity of water has also been attributed to the particles being of a spherical form, in consequence of which configuration they are supposed to slide easily upon each other. The particles of water are so small that the most powerful microscope that has been constructed is incapable of exhibiting them; recourse, however, is had to other contrivances, in order to prove this assertion. Thus, salt and other substances may be dissolved in water, without increasing its bulk, in the same manner as sand or water may be put into a cask containing balls, between the spaces of which the sand or water finds its way. It must be observed, that although this is admitted, it does not sufficiently prove that the particles of water are spherical, for there are other forms of bodies, which, although packed ever so close, yet contain spaces between them.

It is perfectly certain that the particles of a fluid have an adhesion to each other, which decreases as the distances between the particles are increased. Now, caloric or heat tends to separate the particles, and destroy their adhesion, and by this means promotes fluidity. On the contrary, if so much caloric be extracted from a fluid as to allow the adhesion of the particles to operate with sufficient force, the fluid immediately becomes a solid. The honour of the discovery, that caloric is the chief cause of fluidity, is generally ascribed to the late Dr. Black.

Water hardly continues any length of time of the same weight, because, owing to the fire and air which it contains, receives, and gives off, its temperature is continually changing—for the same quantity of boiling water is much lighter than a similar quantity of cold water. This is consistent with the laws of gravitation, which always act upon a body in proportion to the number of particles of which that body consists; and it is the effect that the different degrees of fire have upon water, which renders it difficult to determine its specific gravity, or fix its degree of purity.

It is also a curious fact, that water expands when cooled down to a certain temperature. In a state of ice, it occupies 1-18th more space than at a medium temperature.

From a number of accurate experiments, it is deduced that water is 830 times heavier than common atmospheric air. Some authors, indeed, consider it to be heavier, others affirm it to be less. When the barometer is at 30°, and the thermometer at 55°, water is then 820 times heavier than air; and in such a temperature, a cubic foot weighs 1000 ounces avoirdupois, and that of air 1.22, while that of mercury weighs 13,600 ounces; and for different states of the thermometer, the mercury in the barometer varies its length by the 10,000th part of itself for each degree of temperature. Water is said to change for the same reason by the $\frac{3}{20,000}$ part of its magnitude, by each degree of the thermometer.

With the properties of the different kinds of water we do not interfere, as they do not affect the laws and motions of fluids generally; but we may be allowed to observe, that sea-water is about three parts in 100 heavier than pure or distilled water; its tem-

perature, at considerable depths, is from 34 to 40 degrees, but near the surface it is much the same as the air.

It has been stated, in the commencement of this chapter, that Hydrostatics treats of the equilibrium of non-elastic fluids, such as water. However, water is not exactly incompressible; for it has been found from experiment, that when the barometer is at 29½, and the thermometer at 50, the compression of the following liquids is—

Spirits of wine,.........	60	parts in a million,			or 1-16666th	part of its bulk	
Oil of olives,............	48	”	”	”	or 1-20416.6	”	”
Rain water,...............	46	”	”	”	or 1-21956.5	”	”
Sea ditto,.................	40	”	”	”	or 1-25000	”	”
Mercury,..................	3	”	”	”	or 1-33330	”	”

Now it will be observed, that the compression of these fluids is extremely small, so much so, that it leads us to doubt whether it could be accurately measured. Some later experimentalists have endeavoured to prove that water is much more compressible.

The nature or constitution of a fluid is very different from that of solid bodies. When solid bodies are subjected to compressing forces, they undergo a proportional contraction, and they recover their original volume when the force is withdrawn, if it has not been such as to destroy the cohesion of the particles; for when the force is sufficient for this purpose, the solid is crushed in such a manner that it cannot resume its former shape and dimension. If we take a fluid, and subject it to the greatest possible compressing force, its constitution will not be altered in the slightest degree, the particles will come together, and again resume their original situation.

Water also transmits equal pressures throughout the whole space in which it is confined, upon its being subjected to a pressure at any one point, which is not the case with solids. These press only in the line of the direction of the weight. If the pressure be downwards, the body has no tendency to press horizontally on the sides of the vessel containing it, unless the force or pressure be such as to crush it, destroy its cohesion, or reduce it to particles. Now these particles (we should suppose) will stand in the same relation to one another, and have the same transmittive power in proportion to their magnitude. Of course we infer, that the aptitude of the particles of all bodies to transmit equal pressures, is inversely as their size, as a fluid whose particles are twice as large as those of another, will possess only half the transmittive property. This property is supposed to be owing to the very minute size and form of the particles.

Equilibrium and Pressure of Fluids.

Definition.—A fluid is a body so constituted, that its parts, which are very minute, are ready to yield to any force or pressure, however small, which acts upon it, and by so yielding are easily moved among themselves.

Proposition 1*st.*—Fluids do not propagate their pressure in right lines only, but equally around in all directions, for every particle is pressed by those which surround it, and it equally presses upon them; these press upon others, which again press upon those bodies which they touch—this pressure being carried obliquely in every possible direction. This is proved by the immersion of a soft body in a fluid enclosed in a vessel, which, though strongly compressed, still the original form will not be destroyed.

Prop. 2d.—A fluid is not at rest unless when its surface is perpendicular to the lines of gravitation, *i. e.* in the plane of the horizon. If the directions of gravity be parallel, then the surface of the fluid is a plane; but if they converge to one point, as the centre of the earth, the surface of the fluid is a portion of a spherical surface, having that point for its centre—because, were one part of the surface to be raised, and another depressed, and the force which caused this depression removed, the gravitating force would act upon the part which had been raised above the common level with a greater power than upon that which had been depressed, because there is a greater number of particles in the one case than in the other between their surfaces and the centre of gravitation; the particles which were raised or forced above the common level would then descend, and as they press equally, the particles of the depressed portion would be raised to make room for the others. When this motion commences, a momentum takes place, and the particles which before were below the common level, might rise above it; but they would in like manner descend again, the others again rising a little, *vice versa;* and after vibrating in this way for a short time, they would come to a state of rest, with their surfaces in exactly the same plane, and at the same distance from the centre of gravitation. Hence, water will always rise to the same level, or endeavour to have every part of its surface equally distant from the centre of the earth. If there be two vessels placed at unequal heights, and filled with water, and if a pipe be opened which communicates with both, the gravity of the water in the vessel which is higher will cause it to press upon the bottom of the water in the other, so that it will run over the edges of the vessel, until the surface of the water in the higher vessel and that in the lower reach the same level; all motion then ceases, and the water in the two cisterns and pipe will be at rest.

Prop. 3d.—A fluid being at rest, the pressure upon a particle at any depth is singly as the depth; for the particles in the stratnm *a* (*Plate* IV. *Fig.* 80) are pressed by those of the strata *b c d e f*; but the stratum *g* is pressed not only by strata *b c d e f*, but also by the stratum *a*; and the particles in stratum *c* are pressed by those in strata *d e f*; the pressure on any particle *c* is three; now the pressure on the particle *g*, which is twice as deep below the surface, will be six; and so on.

Prop. 4th.—The bottom of a cistern, containing a fluid, is pressed upon by that fluid in proportion to its perpendicular height, and it is pressed *out* by the fluid in every part in proportion to its depth below the surface; *or*, the pressure on every part is as the perpendicular height of the fluid above that part. Thus the vessel A B C D (*Plate* IV. *Fig.* 81) is filled with water up to the top or level A D; then the pressure on every part of the bottom is as the perpendicular height of the fluid, as B A, as shewn in the last proposition; for the lower stratum of particles, being pressed by all those above it, will press upon the bottom of the vessel with its own weight, together with the pressure of the superincumbent strata, independent of the number of particles in the upper strata. The pressure on the bottom of the vessel is therefore as the height of the fluid, without regard to its quantity, *i. e.* that there would be no more pressure upon the bottom of the vessel B C, although the end D C were placed in the position of the doted line C *e*, enlarging the vessel to the capacity A B C *e*, and thereby enabling it, when filled to the level A D *e*, to hold the additional quantity of water D C *e*. But the pressure upon the

the bottom B C is not diminished, although the end D C were laid in the position C g, in which case the actual quantity of water is diminished, it being only A B C g when filled to the level A g. Hence, the pressure on the bottom B C of the cistern A B C g is the same as that on B C when the cistern is in the form A B C D, and it is still the same when it is in the form A B C e, the perpendicular height of the fluid being the same. Now, the pressure of the fluid to burst out the side A B increases, from nothing, at the top, and presses in every direction alike; then it follows, that if the vertical pressure on the bottom at B is A B, the pressure on the side or end at the bottom B is also equal to A B. Now, if we make B E = A B, B E will represent the pressure on the side A B at the bottom of the cistern; the side pressure at the top A begins at A, the upper stratum of particles, at the upper edge of which the pressure is nothing; but it increases on every part below that, directly as the distance down, as at i, for example, it is A i. This will be represented in its proper direction by the line $i\,k$, that being the measure of pressure at the point i. If we draw the line A E passing through the triangle, A $i\,k$ will represent the whole pressure on the part of the cistern A i; in like manner, the pressure at any other point h is as A h. Now, as $h\,j$ is equal to A h, so is the triangle A $h\,j$ A equal to the whole pressure on the end of the cistern above the point h; for the same reason, so will the triangle A E B represent the ultimate pressure on A B; and if E B = 10, and $h\,j = 8$, then $i\,k = 6.4$; for $10 : 8 :: 8 : 6.4$. The pressure on any part of the bottom is the same, whatever may be the capacity of the cistern, but the weight of the cistern on the props or supports B and C (supposing B and C to be props) is very different.

As some of our young readers may wish to prove experimentally that the pressure on the bottom of a vessel is as the perpendicular height of the fluid, without regard to its quantity, that is, that the pressure upon a given portion is as the area of that portion multiplied into the perpendicular height of the fluid above it,—Take a piece of board, as A B C D (*Plate* IV. *Fig.* 82), and insert into it the conical part of a filler, or the like, as E G; also let F H be a tube of the same diameter as the narrow point of the filler at G; fit a valve V on the bottom of the vessels; erect the frame L L; make two pullies P P′ run round immediately above the vessels; fix a cord to the two valves or bottoms of the vessels, and pass them over the pullies P and P′; attach a weight W to the cord which passes over the pully P, which is just sufficient to counterbalance the weight of water in the tube F H, when it is filled up to the level J. If W be not heavy enough, of course the weight of the water will push out the valve or bottom V; but by trying it two or three times, the weight W may be so adjusted as just to be able to hold up the bottom when the water is filled up to J. Take an equal weight W′, and attach it to the end of the cord which passes over the pulley P′, and holds up the bottom of the vessel E G; fill this vessel with water to the level I J, and it will be found, that although the one vessel contains double or triple the quantity of the other, yet the same weight W′ will be sufficient to hold up the bottom of the vessel, because the area of the bottoms of the two vessels is equal, and the perpendicular height of the fluid is the same in both. The cylinder represented by the dotted lines in the vessel E G, is the mass of water which acts with its weight on the bottom. This

is exactly equal to the cylinder of water in the tube F H, and these are equal in all vessels when the areas of the base on which they stand, and the perpendicular height of the fluid, are also equal, whatever may be the size of the upper part of the containing vessels. Hence, if the bottom of a vessel containing a fluid only suffers a pressure as its area multiplied into the perpendicular height of the fluid, the sides of the vessel must bear the weight of the rest of the fluid.

Prop. 5th.—The pressure on the sides of a vessel, to burst them out by the gravity of the fluid which they contain, is as the perpendicular height at every part, and the angle of the sides; and as the angle of the side from the bottom is increased, so is the side pressure diminished. Let A B C D E (*Plate* IV. *Fig.* 83) be the plane of the bottom of a river; let B F be the inside slope of a mill-dam or the like; let A G be the perpendicular depth of the water, G F being its surface. Now, let us consider the effect and direction of the pressure of the water to burst out the dam at any one place, suppose I. By the proposition, the pressure of the fluid, to burst out the side of a vessel, is as the perpendicular height of the fluid and the angle of the sides of the vessel. When the angle F B A is a right angle, then is the side pressure the greatest possible; for as the angle A B F is increased, the side pressure is diminished. The pressure at the spot I is as the perpendicular height of the fluid above it, as I J. This may be considered the vertical pressure of the fluid on that part of the plane B F; but the fluid tends also to press it out in the direction H I, which is at right angles to I J. Draw I G at right angles to B F, and by the laws of dynamics, the pressure is every where directed perpendicularly against the resisting plane; G I is therefore the direction of the pressure at I. Next draw G H, perpendicular to the surface G F; then if I J be the measure of the vertical pressure, H I is that of the horizontal or side pressure of the fluid upon the plane B F. The line G I is called the resultant of both, for the square of G I is equal to the sum of the squares of H I and J I (47th *Prop. of Euclid.*) Next, let us suppose the plane of the dam to incline with a greater angle from A B, as A C K. In this case there will be a greater weight of water on the dam C K than there was on B F. For example, the weight of water on the plane B F above the point I, will be represented by the triangle F I J, and that on that part of the plane C K by the triangle K L O; but the pressure on any point L, of the plane C K, is as the perpendicular height L O; and the resultant of the horizontal and vertical pressures is the line L M, which is perpendicular to C K. Draw M N parallel to L O; then if H I represents the side pressure on the plane B F, N L will represent the side pressure on the plane C K; and the side pressure is still farther diminished on the plane D P, it being only S Q; and it will continue to decrease as the obtuse angle A D P is enlarged, or the angle E D P diminished. If the angle of the inclined plane from the base A C, prolonged as A C E, is 45 degrees, then are the vertical and side pressures equal to each other, as in the plane C K, where the angle E C K is 45 degrees, and the side L O equal to the side N L.

Now we have shewn (*Prop. 4th*) that the pressure on every part of the mill-dam will be as its perpendicular depth below the surface, and that the whole pressure is as half the square of the depth, that is, the triangle A E B, or K C R, in the last figure.

If we make R K the inside of the dam, K C may be the other side, if the materials which compose the dam represented by the triangle K R C K, be of an equal weight with the water, because here the resistance is, in every part, equal to the pressure; it is also the same, although we make C K the inside of the dam. If the materials be heavier than water, as stone, whose specific gravity is about twice that of water, then a less proportional breadth for the base of the mill-dam will be required; which may be found thus:—As the weight of the material is to the square of the perpendicular depth, so is the weight of water to the square of the breadth of the base. Let D be the perpendicular depth $= 10$ feet, the weight of a cubic foot of water $= 1$, and that of a cubic foot of stone $= 2$; then $D_2 = 100$, and $2 : 100 :: 1 : 50$. Now the square root of 50 is about 7; then 7 feet is the breadth of the base. Of course, if the weight of the material be four times that of the water, half the perpendicular depth is the breadth of the base, viz. 5; for the square of 5 is only 1-4th part of the square of 10, $4 : 100 :: 1 : 25$. In general, it will be proper to make the sloping side the inside of the dam, because by this means the horizontal pressure is reduced, as shewn above; but we would recommend both sides to be sloped.

Scholia.—We have now to shew the application of the principles laid down in the preceding propositions, to a subject more immediately connected with shipping than the above, *i. e.* in the construction of dock-gates.

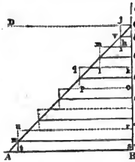
Let it be required to construct a couple of gates for a lock of 32 feet wide, the greatest rise of the tide being 18 feet. The arch of dry dock gates is 1-5th of their breadth, and 1-5th of $32 = 6$ feet 5 inches nearly; but if we make the arch 6 feet, then the breadth of each gate will be 17 feet.

Having ascertained the breadth of the gates, we shall calculate the pressure of the water on one of them, and then consider the strain on its different parts, and determine the strength of the beams, or horizontal cross pieces of timber, of which the gates are to be made.

For the pressure on the gate.—We have shewn (*Prop. 4th*) that the pressure of water on a vertical plane is as half the square of the depth of the fluid, that is, the triangle A E B. Now the given depth in this case is 18 feet; then $18^2 = 324$, and $\frac{324}{2} = 162$, half the square of the depth; then 162×17, the breadth of the gate, $= 2754$ cubic feet, the pressure; and if we divide it by 35, we shall have the pressure in tons, because 35 feet of salt water is equal in weight to 1 ton; $\frac{2754}{35} = 78$ tons 13 hhds. 3 qrs. nearly, for the whole pressure or weight of water on one of the gates.

We have now to consider the proportion of pressure on the different beams. Supposing them to be placed at equal distances from each other, and 3 feet from centre to centre, as in the under figure, where A B is the cell of the gate, B C the edge of the gate, and C D the surface of the water; the depth C B is 18 feet; *b c d e f g* is the centre of the cross beams; they are 3 feet asunder from *b* to *c*, from *c* to *d* being 3 feet; each beam will also have 3 feet of surface of the gate to support, that is, the distance C *h*, *h k*, *k o*, &c. Now the mean depth of the portion C *h* is C *b* or *j v* = 1 foot

6 inches, which is also the mean pressure on C h, the first 3 feet of the gate under the surface; therefore we must multiply $b\,v$ by C h, for the pressure on C h. We shall then have the rectangular figure C $h\,i\,j$, which is equal to half the square of the depth, and so on, for the pressure on every other beam $c\,d\,e$, &c. Thus,—



	Feet. In.		Feet. In.			Feet.
$b=$	1 6	$\times 3=$	4 6	$=$ C $h\,i\,j$;	now $\times 17$, the breadth of the gate, $=$	76.5
$c=$	4 6	$\times 3=$	13 6	$=h\,k\,l\,m$, and	$\times 17$ .... $=$	229.5
$d=$	7 6	$\times 3=$	22 6	$=k\,o\,p\,q$, and	$\times 17$ .... $=$	382.5
$e=$	10 6	$\times 3=$	31 6	$=$ the pressure at e,	$\times 17$ .... $=$	535.5
$f=$	13 6	$\times 3=$	40 6	$=$	$\times 17$ .... $=$	688.5
$g=$	16 6	$\times 3=$	49 6	$=$ pressure $r\,s\,t\,u$ at g	$\times 17$ .... $=$	841.5
			162 0			2754.0

Now, by adding the proportional pressure at all the different depths $b\,c\,d$, &c., we find that it amounts to half the square of the whole depth, that is, 162. In the former case, we multiplied this by the breadth of the gate; but in this, as we want to find the pressure on each beam, we must multiply all the pressures, which make up 162, by the breadth of the gate, which gives the pressure on each of the beams respectively; and if we add all these, it gives the same as before, 2754.0, which divided by 35, gives as before for the weight on the gate. But the pressure on the different beams is—

$b=$ 76.5;	these divided by 35	$=$	2.109	tons nearly.
$c=$ 229.5	... ...	$=$	6.560	
$d=$ 382.5	... ...	$=$	10.931	
$e=$ 535.5	... ...	$=$	15.588	
$f=$ 688.5	... ...	$=$	19.673	
$g=$ 841.5	... ...	$=$	24.045	$=$ 24 tons, 0 hhds. 2 qrs. nearly.
2754.0		$=$	78.906,	pressure on the whole gate.

We now find that the pressure on the lower beam of the gate is about 24 tons. We have next to find what should be the square of a beam, 17 feet long, to support this weight. Suppose it an oak beam: we can easily find the strength of the nearest beam to this length in the tables of Buffon's experiments. We may take that numbered 75 and 76, which beams were 17 feet long and $8\frac{1}{2}$ inches square; these broke with 17,620 lbs. suspended in the middle of the length; but had the load been equally diffused over its whole length, as is the pressure on the dock-gate beam, then, according to the principles of the stress of timber, it would have required 35,240 lbs. to have broken it—about 15 tons. Now, we must have a beam which will be at least four times as strong as this; therefore, if we quadruple its momentum, and take the cube root of the sum, it will be the side of the required beam.* In a similar man-

* It must be observed, that the lower beam of the gate is supported against the pressure by the cell which forms the bed or building; therefore it does not require to be so strong as if it were only supported at each end;

ner the other beams may be proportioned to the pressure which they will have to sustain at the different depths; or if necessary, they may be all of the same size, but placed proportionally closer as they approach the bottom of the gate.

We have a remark to offer here on the pressure of fluids, which, from its obvious principle, seems not to require to be considered as a separate proposition. If a surface be opposed to the pressure of a fluid, there is one point in that surface against which, if a force equal to the whole pressure of the fluid on the surface be applied in the opposite direction, it will balance it, and counteract the whole pressure of the fluid. This point is called the centre of pressure; and as it is no other than the centre of gravity of the surface when acted upon by the different pressures which make up the whole pressure, it may be very easily determined. Thus, suppose it is required to find the centre of pressure of a gate 17 feet in breadth, 18 feet being the depth to which the water rises, the ultimate pressure on which has been determined. We have before laid down the principles for determining the centre of gravity of any body, (*See Chapter* II. *page* 21); and accordingly, dividing the surface of the gate into portions of 3 feet in depth from the cell or bottom to the top or surface of the water, we have the pressure on each portion from the bottom, (of which there will be six, $\frac{18}{3} = 6$), by the last example; and taking these respectively from the bottom, the centre of gravity of the first 3 feet of depth is 1.5 feet, and the common interval being 3 feet, the centre of gravity of the next is 4.5 feet from the bottom; of the next, 7.5 feet; and so on.

			Cubic Feet.		Feet.
Pressure on	1st 3 ft.	from the bottom	= 841.5 ×	by the distance of its centre of gravity	1.5 = 1262.25
Ditto,	2d	ditto,	= 688.5 ×	....	4.5 = 3098.25
Ditto,	3d	ditto,	= 535.5 ×	....	7.5 = 4016.25
Ditto,	4th	ditto,	= 382.5 ×	....	10.5 = 4016.25
Ditto,	5th	ditto,	= 229.5 ×	....	13.5 = 3098.25
Ditto,	6th	ditto,	= 76.5 ×	....	16.5 = 1262.25
			2754.		16753. 5

And $\frac{16753}{2754} = 6$ feet, the distance of the centre of pressure from the bottom of the gate as required, which is 1-3d of the depth from the bottom, or 2-3ds from the top. Now from this it appears, that should the upper part or hinge of a flood-gate seem to be weak, or any extraordinary flow of the tide be expected, which might injure the gates of a dry dock, a very strong prop placed against the gate, in the middle of its breadth, and 1-3d from the bottom, would support it against the expected pressure. The centre of pressure of rectangular surfaces being at 1-3d from the bottom or 2-3ds from the top,

for according to the above illustration, the momentum of the beam of 17 feet long and 8½ inches square, (which had an ultimate strength of 15 tons), is 614; and 614 × 4 = 2456, the cube root of which is 13½ inches for the side of the lower beam, but which, on account of being supported by the cell, is unnecessarily strong. Mr. Barlow's rule gives nearly the same result. Thus, $1420 \times 13.5^2 \times 54$, which is four times the breadth = 13955760, and 17 feet = 204 inches; then $\frac{13955760}{204} = 68415$ lbs. = 30 tons; and $30 \times 2 = 60$ tons: Consequently a beam of 17 feet long, 13½ inches square, is four times as strong as one 17 feet long and 8½ inches square.

we have only to multiply half the square of the depth by the breadth of the gate for the whole pressure on the same, and apply a prop or force equal thereto in the centre of the breadth, and 1-3d from the bottom, in order to support or counteract the whole pressure of the water on the gate.

Prop. 6th.—Equal and unequal columns of a fluid balance each other; and if they are of the same density, their surfaces are on the same level; also, the pressure of a fluid on the bottom and sides of a vessel may be very great, while the weight of the fluid is very small.

If we take a bent tube of equal diameter throughout, and holding it vertical, fill it with water, it is evident that its surface will be on the same level in both limbs of the tube, *i. e.* the line which joins these surfaces will be horizontal. But if two different fluids are poured into the bent tube, their heights above their place of meeting will be reciprocally as their densities. Thus, if the fluid in the limb A (*Plate* V. *Fig.* 85) be double the specific gravity of that in the limb B, and their point of meeting be C, then C F will be double D E, and it will always be so, whatever be the difference between the diameters of the two legs; for the pressure of fluids depends upon their perpendicular heights, and not at all on their quantities. The consequence of this is, that any quantity of fluid, however small, will balance any quantity, however large, which does not take place from a mechanical, but from a hydrostatical princinciple. Suppose we have a bent tube A E B F C (*Plate* V. *Fig.* 86), the leg B F C being 5, 10, 20, or any number of times the diameter of the leg B E A, and also that there is a thin division in the bottom of the tube, as at B. Let the leg A E B be filled with water to the level E; now the pressure on the division B is its area multiplied into the perpendicular height of the fluid above it. As action and re-action must be equal, we require a force equal to B E to support the water at the same height; we must therefore fill the other leg B F C to the same level E F, when both sides of the division B will suffer equal pressures, as we suppose it to be very thin, and both sides to possess equal areas; and as the perpendicular height of the fluid in B C is equal to that in B A, the division will be equally pressed; it will therefore remain at rest, even supposing it not to be attached to the tube. But as the water stands at the same level in both tubes, if the division be removed, and the fluids allowed to meet at B, the water in the small leg will still balance that in the larger one; or, what is the same thing, a weight or solid body applied at the division B, equal to the neat weight of the water in the leg B F C. Hence it follows, from this principle, that if A B C D (*Plate* V. *Fig.* 87) be the section of a strong cistern, E F a board which exactly fits it, and *a b* a small pipe passing through the board at *b*; if we suppose the board E F to be fixed where it is represented, and water to be poured down the small pipe, so as to fill the space G and the pipe up to *a*; then the pressure of the fluid thus introduced into the space G, to burst the cistern at any part, as *e*, *f*, or *g*, is the same as if the board E F were removed, and the cistern filled with water to the level A D. The small tube *a b*, when filled with water, would, as has already been shewn, balance another tube of any diameter, when filled up to the same level as A E F B. But again, if we suppose that there is no water above the board E F, but that the pipe *a b* is full, and the board not

fixed, then it will ascend in the cistern, and carry up with it a weight which is equal to the volume of water A E F D; the space G would be continually enlarging by the ingress of water through the pipe *a b*, which is supposed to rise with the board; and when the board had risen (by pouring water into the pipe *a b*) to A D, and the pipe still kept full, then the pressure at *e*, *f*, or *g*, would be twice as great as it was before the rising of the board or piston E F; for, as has before been noticed, the pressure on every part is as the perpendicular height of the fluid, and not at all as its quantity; and it will appear evident, that if in place of the tube *a b*, we use a tube *k l*, the power to raise the board E F will continually diminish, as the board rises nearer the surface or mouth of the pipe *k*.

A very slight examination of these principles will be sufficient to convince us of the immense power which may be produced from a hydraulic machine of this kind. But before we attempt to calculate it, we shall notice the weight of the fluid. Dr. Hutton has given the pressure of water for every foot of height to be 1000 ounces, = about $62\frac{1}{2}$ lbs. avoirdupois. Now, as there are 2240 lbs. in a ton, by dividing this by 62.5, we shall find the number of cubic feet equal to the weight of one ton, which is about 35 feet 10 inches; and as salt water is about three parts in a hundred heavier than fresh, a less actual quantity will weigh a ton; this is about 34.78 feet, = 34 feet 9 inches. Farther, it will be found that 360 inches of fresh water will weigh about 13 lbs.; hence the pressure on a square inch $\left(\frac{360}{12} = 30\right)$ 30 feet under the surface is 13 lbs.; or, a column of water 30 feet high weighs 13 lbs. if the area of its base is one square inch. Having found the weight of water, we may give an illustration of the force of hydrostatic pressure. Let A B C D (*Plate* V. *Fig.* 88) be the section of a short cylindrical vessel; let P be a piston fitting it perfectly tight; suppose the area of the bottom of the piston is one foot; next let *e* B G be a small pipe, the area of the mouth of which (at *e*) is one inch, and let the height *e* G be 60 feet; then, if we throw water into the cylinder through this pipe, it will raise the piston P with a force proportionate to the height *e* G, because the water in the pipe *e* G would balance a column of water, whose base is the piston, and height *e* G. Now the weight of this column is the weight of 60 feet of water, = 3750 lbs.; therefore, if the weight of the piston P and the ball W be together less than 3750 lbs., they will be raised up by the weight of the fluid in the small pipe. The force of any machine of this kind may be easily calculated: Thus—As the area of the small pipe at *e* : to the weight of water in the small pipe : : the area of the piston P : the weight which it will rise with; so that if we calculate the force of the above machine in this manner, we shall find it to be the same as before. The area of the small pipe at *e* is 1 inch, and its height is 60 feet (the weight of 30 feet of water in an inch-pipe is 13 lbs.) = 26 lbs. nearly, and the area of the piston is 144 inches: Then as 1 : 26 : : 144 : 3744 lbs., the weight which would be raised. But of course an allowance must be made for the friction of the piston against the cylinder.

Scholium.—The proposition we have now laid down, and which is confirmed by experiment, is generally called the Hydrostatic Paradox. In the example of its applica-

tion to the raising of great weights, we have only considered the pressure to be produced by the application of a little water in a small tube; but it will appear evident, from a consideration of the principle of the machine, that by using the working of a piston in the small tube, the force may be considerably increased; and the smaller the pipe the better, as the power of the piston will in consequence of this be greater. By this means, if we could find materials sufficiently strong, any weight whatever might be raised; and indeed very great pressures are actually produced by an engine of this kind, known by the name of Bramah's Press, and is that which we mentioned in our chapter on the mechanical powers, as said by some to constitute the seventh mechanical power. It is there called the hydraulic press, which is its general name. A hydraulic engine commonly means any engine moved by the gravity or impulse of water.

X *Prop. 7th.*—A solid body immersed in a fluid will displace a quantity of that fluid equal to its own bulk; and the weight of the quantity of fluid so displaced will be equal to the weight of the solid, if the specific gravity of the body and the fluid are also equal; and if the specific gravity of the body be twice that of the fluid, then the weight of the fluid displaced will be half that of the body itself. But if the specific weight of the body be less than that of the fluid, then the body will sink only so far, that the weight of the fluid displaced is equal to the weight of the whole solid: For the pressure of the whole body upon the fluid under it is just what would be produced by a body whose density is the same as the fluid, and whose magnitude is equal to that part of the body immersed; or, the pressure of the body on the fluid under it is equal to the pressure of as much water as the bulk of the part of the body immersed.

Bodies of the same density as the fluid in which they are immersed and suspended, seem to lose all their weight, and they neither endeavour to ascend nor descend, but remain at rest in any part of the fluid. If the body be heavier than the fluid in which it is immersed, it will descend with a force equal to its excess of weight above that of an equal bulk of the fluid: If it be lighter than the fluid, and be pressed down by some external force, and then left to itself, it will ascend with a force equal to the excess of the weight of an equal bulk of the fluid over that of the body.

If a body float on fluids of different densities, the part of the body which will be immersed in each fluid will be respectively as their densities—as a ship, for example, which displaces 10,000 cubic feet of salt water will displace 10,300 feet of fresh water, salt water being about 3 parts in 100 heavier than fresh water.

Scholium.—As the principles laid down in the above proposition will appear consistent upon a very short consideration, any farther demonstration is unnecessary. For example, it must appear quite evident that it is the upward pressure of the fluid on the bottom of a body which is lighter than the fluid, which causes it to rise from the bottom of the vessel when it has been pushed down; for although the water presses also on its upper side, yet this is with less force than it does on its lower side. That this must be the cause of its floating upwards may be easily proved; for if we take a piece of wood, and lay it flat upon the bottom of a vessel, with a little grease put round its edges, so as to prevent the water from getting under it, the vessel

may then be filled with water; yet the piece of light wood will not rise to the top. In fact, this is exactly the case with ships, which, when they have settled into soft mud, will sometimes not float up, although the tide should flow to a considerable height above their common line of floatation.

The pressure of fluids being in proportion to their height or depth, and acting with the greatest force perpendicularly against the surfaces of bodies immersed in them, do, by this pressure against the under side of all bodies which are lighter than the fluid itself, bear them up, and cause them to swim; for if they are sunk by the application of some force to them, they will ascend to the surface again when that force is removed; and that this upward pressure is as the depth, and that at 10 feet deep it is ten times as great as at 1 foot deep, may be very easily proved. Thus, suppose we have a log of timber 12 inches square and 20 feet long, its sections being all equal to each other, and its sides parallel to each other; let it be laid on the surface of the water, with its top and bottom sides parallel to the surface; then, if its specific gravity be half that of the fluid, it will only sink 6 inches, because the quantity of the fluid displaced will be equal to the whole weight of the log. Now, as its sides are parallel to each other, they will be at right angles to the surface of the fluid; and as the pressure of the fluid is at right angles to the surfaces on which it acts, the sides of the log will be pressed together, but this pressure has no tendency whatever either to raise or depress the log; therefore its whole weight must be supported by the upward pressure of the fluid against its under horizontal side. Its centre of gravity will be at the surface of the water, and in the middle of the length and breadth of the log. Now let us suppose it to be put down into the water in a vertical position, it will immediately sink till it immerses half its length, there being only one square foot of surface to be acted upon by the vertical upward pressure of the water. In the first position, it had 20 square feet of surface to be pressed upon upwards, but this was only at 6 inches below the surface; now we have 1 square foot at 10 feet below the surface to be acted upon by the upward pressure of the fluid, but the square foot at 10 feet below the surface is 20 times as deep below the same as the bottom of the log was in the former case. In both these cases, the weight of the log and the pressure of the fluid balance each other, and an equilibrium is obtained, which proves that the pressure on 1 square foot at the depth of 10 feet below the surface is equal to the pressure on 20 square feet at the depth of 6 inches below the surface. This is always the case, whatever be the form of the bodies immersed. It is generally known, that all bodies lighter than water, *bulk for bulk*, will float or be borne upwards by the fluid. This is often considered to be the effect of some secret law or principle in the nature of fluids; but it is owing to its being hard and smooth, by which it is, to all appearance, divested of friction with regard to the particles moving or changing place among each other. These properties allow it to act with its whole weight, in all directions, on every opposing surface. This is clearly demonstrated by the three figures A B C (*Plate* V. *Fig*. 89.) Let *Fig*. A be a rectangular prism, 2 feet long, 6 inches thick, and 12 inches in breadth, containing one cubic foot of fir or any other kind of timber, and having any weight suspended from its lower end, so that it shall, together with the weight suspended from it, be nearly equal to the

weight of one cubic foot of water, and float, with its upper end exactly level with the water into which it is immersed. Now it is certain, that as the sides of the piece of timber are all parallel to each other, and supposed to be perfectly vertical to the surface of the water, the water acting against these sides can have no effect whatever either in raising or depressing the body; therefore the whole action of the fluid in supporting it must be exerted in a vertical direction against its lower end, as is proved by the floating of the log of timber in the two positions, as above described. Now the area of the end of the body is 72 inches, and 72 multiplied by 24 inches, the depth, produces 1728 cubic inches, the contents of the body, and also the quantity of water displaced,—the weight of which is equal to that of the body and weight suspended from its lower end, which are supported by the vertical pressure of the fluid upon the lower end of the figure.

But it is evident, from the manner in which the water acts upon the body thus immersed, that if any prism or cylinder be placed with its lower end close to the bottom of a vessel, in such a manner (as before observed) that the water cannot enter under it; then, although the same quantity of water is displaced as if it were floating at any distance from the bottom, it will have no tendency to float upwards, although it is much lighter than water, but will remain with its whole weight upon the bottom. Although it were possible to effect an opening exactly under it for the admission of the atmosphere to act as a counter-balance to that on the top, it will still remain in the same state, unless a force equal to its own weight be applied to lift it.

Again, supposing *Fig.* B to have the form of a wedge 2 feet long, 12 inches square on the head, and brought to a thin point at the lower end, it would contain one cubic foot also, and displace the same quantity of water, and bear the same weight suspended from its point, when floating with its head end just level with the surface of the fluid. Now its depth of immersion is 2 feet, and the action of the water being as half the squares of the depth, the tapering side is pressed with a weight equal to 2 cubic feet of water; but observe, that it can only act with a force equal to half its weight, in an upward direction, to support the wedge from sinking, as is seen by the parallelogram of forces. Therefore, the whole weight of the fluid that is exerted in supporting the body, is that of one cubic foot of water, the quantity displaced.

In *Fig.* C, the wedge is immersed with its head end downwards, and the same weight suspended from it, which will also sink it until its point is just level with the surface of the water. There is also the weight of two cubic feet of water acting upon the inclined side of the wedge; but as its position is now reversed, so is the direction of the forces changed, and the weight of the fluid will now produce the same effect in depressing *Fig.* C, as it did in supporting *Fig.* B. So if *Fig.* C be pressed downwards with a force equal to the weight of one cubic foot of water in addition to its own weight, there must be a force equal to the weight of two cubic feet of water acting in a vertical direction upon the head or lower end, one of which will counteract the downward pressure on the sloping side, the other the weight of the body immersed, to prevent it from sinking. The three figures A, B, and C, are all solids of the same magnitude, displacing the same quantity of water, and supporting the same weights, in whatever

floating situation they are placed, although the surfaces exposed to the fluid are very different, and the ultimate pressure which each must sustain in the same proportion. *Fig.* A presents a surface of $6\frac{1}{2}$ feet, B = 6 feet, C = 7 feet, and the weight of water sustained by each is A = 13 feet, B = 12 feet, and C = 14 feet. The pressure of the fluid on the vertical sides is of no service in supporting the bodies, these being entirely supported by the vertical pressure against the bottom, and such parts as are more or less inclined from the same. The body C, if placed close to the bottom of any vessel, and the water prevented from getting under it, would require a force equal to double its own weight to raise it from the bottom, although a free action of the atmosphere were permitted under it; because it is pressed downwards, not only by its own weight, but also by an additional pressure, equal to the weight of the body.

The pressure on the end A B (*Plate* IV: *Fig.* 81) is the same, whatever be the length and breadth of the cistern. The pressure on a dock-gate is not diminished, though a solid wall is built one foot or one inch without it, so that it allows the water to get between it and the gate, and to rise to the same height as before; for the thinnest perpendicular stratum of water of any depth, will produce an equal pressure to the effect of the whole ocean acting at the same perpendicular height; because equal and unequal columns of water balance each other,—a column of water, however small, will balance another column, however large.

If a cistern, one foot square, be filled with water, the whole weight or pressure on the bottom will be the weight of one cubic foot of water = $62\frac{1}{2}$ lbs. Now, the weight or pressure will be the same, if any other body, or a smaller cistern, be thrust within it, although nearly all the water has thus been forced over the edges of the cistern; because the force necessary to hold the smaller cistern down will always be equal to the weight of water displaced, and the thin column of water all round between the two cisterns will balance a column of water equal to the area of the base or bottom of the inner cistern, multiplied by the perpendicular height of the fluid around it.

The failure in raising vessels which are sunk in ground which is sandy or muddy, is often owing to an ignorance of, or inattention to, the principle now illustrated. The general plan is, to attempt to lift the vessel at both ends at the same time; whereas, from what has been said about the tendency of a body to float when the water is excluded from below it (which is the case where a ship is sunk in a soft bottom), and the upward pressure of fluids, it would be more advantageous to raise one end of the vessel first, by which means the water would get under her bottom, and a very slight power only would be required to raise her to any height nearer the surface. We have been induced to throw out these remarks, from the importance of this subject (the raising of sunk vessels), for the benefit of such young shipwrights as have not directed their attention to the principles of hydrostatics, but who may be called upon to exert their professional knowledge in this respect.

From these and similar experiments, it is evident that the pressure of the fluid on the upright part of the sides of a ship, or any other vertical part of the bottom which is immersed, does not tend either to raise or depress her; the whole structure, together with cargo, &c. is entirely buoyed up by the vertical pressure of the water on those parts of

the bottom of the ship which are more or less inclined from the vertical position. We would wish the young shipwright never to lose sight of this important fact. The vertical pressure upon those parts of the bottom which lie inclined or horizontal, is found by multiplying the surface into the perpendicular height of the fluid above its centre of gravity, and allowing about 35 feet of the product for a ton. But the force which this pressure exerts to bear up the vessel, *i. e.* the vertical pressure on an inclined surface, is inversely as the angle of inclination of the surface from the horizontal position: For example, let A B C D E (*Plate* V. *Fig.* 90) be the side and bottom of a vessel; let F G be the surface of the water. Now the pressure is perpendicular to the surfaces on which it acts; therefore, on the horizontal part D E, it is the surface D E multiplied by the depth E G; this pressure is vertical, and we may represent it and its direction by the line H I. The pressure on the portion D C of the bottom, is the surface C D multiplied by the perpendicular depth of its centre of gravity below the surface of the water F G. If L be the centre of gravity of C D, then L *m* is its perpendicular depth below the surface. Now, C D × L *m* may be represented by the line K L, and K L is perpendicular to C D; but K L is not lifting the vessel in a vertical direction, but is tending to push it in the direction K L. But the force K L may be resolved into two forces, the one pushing upwards, as *a* L, and the other horizontally, as *b* L; and the force K L is to that on a horizontal surface as *b* L to *a* L. In like manner, M N is the direction and pressure on the portion B C, and its perpendicular pressure is to its horizontal as *c* N to *d* N; on the portion of the side (which is perpendicular), P Q is the horizontal pressure, and there is no vertical pressure on the same. Hence the vertical pressure on inclined parts of the bottom of a vessel is as the surfaces of these parts multiplied by the depth of their centre of gravity, and by their angles of inclination from the perpendicular.

Prop. 8*th.*—Suppose a floating body to have sunk so far as to displace a quantity of the fluid equal to its own weight, it cannot be at rest unless the straight line which joins the centre of gravity of the body and the centre of pressure be vertical to the surface of the water. The centre of pressure is the centre of gravity of a mass of the fluid, of the form and dimension of that part of the body which is immersed.

Let A B C D (*Plate* V. *Fig.* 91) be the log of timber alluded to in the scholium to our last proposition; let E F be the surface of the water; then, as it is a homogeneous body, G is its centre of gravity, and H is the centre of immersion, being the centre of gravity of the part immersed, *a b* C D. Now, as all bodies fall through their centres of gravity, we conceive the whole weight of the log to be concentrated in that point, and the body tends to descend by its gravity in a line at right angles to the horizon, *i. e.* in the direction G H; but the upward pressure of the fluid on the end D C is sufficient to bear up the log at a depth of immersion *a* D, which is half A D, and we may conceive the whole force of this upward pressure to be concentrated in the point H, and tending to raise the body in the vertical direction H G. Now, the weight of the whole log A B C D tends downwards in the direction G H; the upward pressure of the fluid *a b* C D is exactly equal to the weight of the log, and it tends upwards in the direction H G; therefore these two forces being equal and opposite to each other, de-

stroy each other, and the log A B C D remains in equilibrio, the action and reaction being equal and opposite. We have here a state of equilibrium of a very unstable kind, for the least action or touch would destroy it. A slight breath of air on the part of the log above the water would cause it to incline in the position as shewn in the other figure. Before two forces can destroy each other, they must be equal and opposite. Now we conceive the weight of the log to be the same as in the former position, and to be exerted at the same spot G′, and in the same vertical direction G′ I; we must also conceive the pressure of the fluid the same, exerted at H′, and in the direction H′ L′. A moment's reflection will convince us that it cannot remain in its present position, but will tumble over, and lie with its sides A″ D″ parallel to the surface of the water, when it will come to a state of rest, as represented in *Fig.* 92, where E″ F″ is the surface of the water. Now, if we trace the position of the centre of immersion in this state, we shall find it vertical to that of gravity, as at H″: The body endeavours to descend through G″ H″, but is prevented by an equal force (the upward pressure of the fluid) exerted in the direction H″ G″; it therefore remains at rest, and has now acquired in this state a very considerable stability. When placed in the vertical position, if its stability (which, as we have noticed, is extremely small) is in the least destroyed, it is completely upset, as we have shewn, and has no tendency to regain its former vertical position. But it is quite different in *Fig.* 92, for it will require a very considerable force applied at A″ or D″ to make it incline in any very sensible degree; and when that force is removed, it will again recover its level position, and in fact, if left to itself, will float in no other. The equilibrium in the first case is called the *unstable equilibrium;* in the second case, the *equilibrium of stability*. There is another case of equilibrium in floating bodies—the *equilibrium of indifference*. This depends not upon the position in which the body is placed, but upon its particular form and its homogeneous property. The form of this body is a globe or sphere. Suppose A C B D (*Plate* V. *Fig.* 93) to be its greatest section, G its centre of gravity; then, if it be immersed in a fluid whose specific gravity is double that of the solid, A B will be the surface of the water, H its centre of displacement, and the strength which joins the centre of gravity and displacement, is vertical to the surface of the fluid, and will be in every position which the globe can assume, and also the same whether it is wholly or partly immersed. But the same thing takes place in every solid of revolution if the axis be placed parallel with the surface of the fluid, as in the case of a cylinder floating with its axis horizontally; for bodies of this kind have no tendency to maintain one position more than another, with respect to their rolling or transverse movements. When these vibrations or oscillations take place by disturbing the equilibrium of the floating bodies, the centre of motion is supposed to be in the same place as the centre of gravity of the body.

Prop. 9*th*.—If a body float on the surface of a fluid, the force tending to make it incline is equal to the weight of the body multiplied into the horizontal distance between the line of support and the line of the centre of gravity, that is, the horizontal distance between I and G (*Plate* V. *Fig.* 95). This agrees with the same figure in the last proposition, in which case the line which passes through the centre of gravity

is on the same side of the line of support H as the immersed part C, *i. e.* the part which is deepest immersed; but when the reverse of this is the case, as in *Fig.* 94, where G is the centre of gravity, situate below the point of support, *i. e.* the centre of immersion H, then the weight of the body, multiplied into its horizontal distance H *k* from the line of support, is the measure of its stability, or the force with which it will be brought back to its original position. In considering the stability of floating bodies, we must take the effect of momentum, or the weight of the bodies, multiplied into the horizontal distance between the vertical lines which pass through the centres of gravity and support, either in the affirmative or negative sense, according as it falls to the side of the body which is immersed deepest, or to the opposite side, that is, whether the centre of gravity of the body be above or below the centre of immersion; for in the first case it destroys or lessens the stability, and in the second it is sure to increase it.

Prop. 10*th.* *To find the specific gravity of bodies.*—By specific gravity, is meant the proportional weight of a body to that of an equal bulk of some other, which is made the standard of comparison. This is commonly water, a cubic foot of which is said to weigh 1000 ounces; and the rules for determining the specific gravity are derived from the laws laid down in the 7th proposition. Bodies of the same density as the fluid in which they are suspended lose all their weight, and the weight of the fluid so displaced is equal to the weight of the body. Hence, the difference between the absolute weight of a body, and its weight when entirely immersed in a fluid, is exactly equal to the weight of a quantity of the fluid equal to the bulk of the body. Therefore the weight of the body when weighed in air, lessened by its weight when weighed in water, is the weight of a quantity of water equal in bulk to the body. Hence, the weight of any body, divided by an equal bulk of water, gives the specific gravity of the body. Thus, if the weight of a body when weighed in air is W, and its weight in water W′, then $W - W'$ is the weight of an equal bulk of water, and $W \div W - W$ is the specific gravity of the body as compared to water; when $W \div W - W' = O$, then the specific gravity of the body is neither greater nor less than water. When the body whose specific gravity we wish to ascertain is a solid, and heavier than water, we must weigh it exactly, first in air and then in water, or the like; and say $D = A \div A - B \times C$; when A is the weight of the body in air, B its weight in water, C the specific gravity of the water, and D the specific gravity of the body. But perhaps if we give the example in figures, it will be more easily understood. Let $A = 1000$ ounces; then it follows, that if $C = 1000$, $B = 0$. Thus $1000 \div 1000 - 0 \times 1000 = 1000$. Therefore the specific gravity of the body is the same as that of water. But the rule, when the solid body is lighter than the water, is to take the body and attach it to a piece of metal, so that it may sink in the water; and then say $D = A\,C \div A + E - F =$ the specific gravity of the light body, the letters D A and C standing for the same thing as before, and E being the weight of the metal in water, and F the weight of the compound in water. To find the specific gravity of a fluid, take a body that will sink in the fluid also in water, and put A for its absolute weight, B its weight in water, G its weight in the fluid, C the specific gravity of water. Then $A - G \div A - B \times C =$ the specific gravity of the fluid required.

But as the specific gravities of bodies of almost all kinds have been long known, it will be unnecessary to determine this by experiment, as the following table will be sufficient to exhibit the specific gravity of all common bodies. In this table, water is made the standard, a cubic foot of which weighs about 1000 ounces; the numbers in the columns express the weight in ounces of a cubic foot of the different bodies, either solids or liquids, if we remove the decimal point. Hence, if we have the cubic contents of a block or mass of any of these bodies, and wish to ascertain its weight, we have only to multiply the number of cubic feet by the weight of one cubic foot; and conversely, if we have the weight of the block or mass, we have only to divide it by the weight necessary to make one cubic foot of the same, for the number of cubic feet in the mass.

A TABLE of the Specific Gravity of Bodies.

SOLIDS.		Onyx-stone	2.510	Indian Cedar	1.315	Aqua Regia	1.234
Iridium, hammer'd	23.000	Paving do.	2.415	Cocoa Wood	1.040	Spirit of Urine	1.120
Platina	21.040	Grinding do.	2.142	Vine Tree	1.327	Human Blood	1.154
Fine Gold	19.648	Portland do.	2.496	Oak (green)	1.170	Sack	1.033
Standard do.	18.888	Crystal	2.210	Do. (dry)	.801	Urine	1.032
Lead	11.340	Oyster Shells	2.092	Alder Wood	.800	Milk	1.031
Palladium	11.080	Brick	2.000	Common Water	1.000	Sea Water	1.030
Fine Silver	11.092	Earth	1.984	Bees Wax	.950	Ale	1.028
Bismuth	10.047	Nitre	1.900	Logwood	.913	Vinegar	1.026
Copper, hammer'd	9.000	Vitriol	1.888	Ice	.908	Tar	1.015
Do. cast	8.090	Alabaster	1.874	Ash (green)	.845	Distilled Water	.993
Fine Brass	8.350	Horn	1.840	Do. (dry)	.838	Oils—Hempseed	.926
Steel	7.850	Ivory	1.820	Plum Tree (dry)	.826	Do. Linseed	.940
Iron	7.644	Brimstone	1.800	Elm (dry)	.801	Do. Olives	.915
Pewter	7.471	Chalk	1.793	Yew Tree	.760	Do. Cod-fish	.923
Tin	7.320	Borax	1.717	Crab Tree	.700	Do. Poppy-seed	.929
Cast Iron	7.000	Alum	1.714	Beech (dry)	.700	Do. Walnut	.923
Lead Ore	6.200	Clay	1.712	Walnut Tree	.650	Do. Whale	.923
Copper Ore	5.167	Dry Bone	1.660	Cedar	.613	Do. Lavender	.896
Lapis Caliminaris	5.000	Human Calculus	1.542	Fir	.550	Spirit of Turpen-	
Loadstone	4.930	Sand	1.520	Cork	.238	tine	.874
Crude Antimony	4.000	Gum Arabic	1.400			Oil of do.	810
Diamond	3.517	Opium	1.350	FLUIDS.		Spirit of Wine	.866
White Lead	3.160	Lignumvitæ	1.330	Mercury	14.000	Common Air	.0012
Island Crystal	2.720	Coal	1.250	Do. at 32° Fahr.	13.061		
Marble	2.707	Ebony	1.177	Do. at 60° Fahr.	13.058	STANDARD FOR GASES.	
Pebble Stone	2.700	Pitch	1.150	Do. at 212° Fahr.	13.037		
Coral	2.700	Rosin	1.100	Oil of Vitriol	1.700	Atmospheric Air	1.000
Jasper	2.666	Mahogany	1.063	Oil of Tartar	1.550	Oxygen	1.111
Rock Crystal	2.650	Amber	1.040	Honey	1.450	Hydrogen	0.069
Pearl	2.630	Brazil Wood	1.031	Spirit of Nitre	1.315	Carbonic Acid	1.527
Glass	2.600	Boxwood	1.030	Aquafortis	1.300	Chlorine	2.500
Flint	2.570	Pomegranate Tree	1.351	Treacle	1.290	Nitrogen	0.972

On the Resistance of Fluids.

Having to a certain extent explained the nature and action of non-elastic fluids, under the term Hydrostatics, I shall now consider the laws of the resistance which they present to bodies moving in them. As the science of Hydrostatics treats only of the pressure and equilibrium of fluids, and as there is no body which we can immerse in a fluid but what will be pressed by it, it follows, that if it be made to move, it will communicate motion, first to those particles which are in immediate contact with it, and those again to the surrounding particles.

In discussing briefly the resistance of fluids, we must confess that it is a subject which is involved in very great obscurity. The most eminent philosophers have admitted that there is no part of mechanical philosophy with which they are so little acquainted as the motion of fluids. The difficulties attending this part of our subject may be imagined on perusing the following extract from the celebrated Dr. Hutton's writings :—

"Nor is it strange that the knowledge we do possess of this science should be so dubious and confined, when we consider the many powerful obstacles which continually present themselves in the cultivation of it. The masses, the figures, and the number of particles of a fluid in motion, are particulars with which we are too superficially acquainted, to determine the laws of its motion with any degree of satisfaction."

The term Resistance, in mechanics, signifies an obstruction presented to the movement of a body. Thus, if to a body in motion, a body at rest be opposed, it will retard or reduce the velocity of the moving body in proportion to its weight; but the moving body will impinge upon the body at rest with a force equal to its weight multiplied into its velocity before striking, and this is called its momentum. The momentum of a body at rest is its weight or magnitude, and the resistance which it presents to a moving body is the *inertia* of the matter which it contains. Suppose a body A to move with the velocity v; and suppose a smaller body a to move with a greater velocity V, in the opposite direction; then, on the collision, if $A \times v$ be greater than $a \times V$, the body A will prevail, and both bodies will move in the direction of A with a force equal to the excess of momentum of the body A over that of a'; and the retardation of body A will be in the ratio of its momentum to that of the body a'. If $A \times v = a\,V$, both bodies will remain at rest after they come in contact; action and reaction being here equal and opposite, they mutually destroy each other. This explains the fundamental law of the resistance of solids, and there is here one grand cause, *the inertia of matter*. But the resistance which a body suffers from a fluid in which it is moved, arises from two causes—first, from the cohesion of the particles of the fluid with one another; for every body moving in a fluid, must in its motion through the fluid, separate the particles, and destroy the force of their cohesion, otherwise it would not be able to pass through the fluid; therefore the force of the body is destroyed by as much as is requisite to overcome the adhesion. This, then, is the first cause of the resistance of fluids to bodies moving in them; the second is the inertia of matter which is common to all bodies, and which require a certain force to remove the particles from their places of rest, or the right direction of their course. A particle of a fluid moving with a certain velocity will impinge upon an op-

posing obstacle, with the same effect as an equal particle of a solid body moving with the same velocity. But a mass or bulk of a fluid moving with a certain velocity will not strike an opposing body with the same, but with a less effect or force, than an equal bulk of a solid of the same weight moving with the same velocity; because as the particles of the solid body are united firmly together, the blow is given at the same instant by every particle of the aggregate; but as the particles which compose the mass of the fluid only adhere slightly, they do not act jointly, but one after the other, in close succession, and with continual effort, while motion is continued.

As the retardation to the velocity of moving bodies, when immersed in a fluid, arising from the first-mentioned cause of resistance, the cohesion of the fluid, is the same, whatever the velocity of the body is, if the fluid continue at the same temperature, the same cohesion must always be overcome in passing through the same space, whatever may be the velocity with which it is described. But the space passed through is simply as the velocity; therefore the resistance arising from the cohesion of the particles of the fluid is also simply as the velocity.

The resistance arising from the other cause, the inertia of matter, when the body moves through the same fluid, but with different velocities, is as the number of particles which have to be removed in a given time; and the number to be removed will be as the velocity; if the space passed through be double, then a double number of particles will be removed; hence the resistance is, first, as the number of particles against which the body strikes in equal times, which is as the space run over in the same time, which is as the velocity. But the resistance increases in proportion to the force with which the body strikes the particles, or the force with which the particles strike the body, which is the same thing, that is, their momentum; and this is as their velocity: so that if the velocity of the body be tripled, the resistance is tripled on account of the triple number of particles which has to be removed in the same time. But it will likewise be tripled by reason of its striking against each particle with three times the force; and hence the whole resistance is as the squares of the velocity: for a body moving in a fluid meets with resistance, partly in the ratio of its velocity, and partly in the duplicate ratio of the same. Of course we are neglecting that which arises from the cohesion of the particles of the fluid, because in water it is so small in comparison to the other resistance, and since it only increases as the velocity, while the latter increases as the squares of the velocity; and as the more the velocity increases, the difference between them is the greater, it is not to be taken into account unless perhaps for very small velocities. Therefore, if a vessel sail through the water at the rate of three miles per hour, her resistance may be represented by $3^2 = 9$; but if her speed be increased to six miles per hour, the resistance at this rate is $6^2 = 36$: it is therefore four times what it was before; hence a double velocity creates a quadruple resistance, and a quadruple power can only produce a double motion.

Persons unacquainted with this fact are apt to suppose, that by spreading a double quantity of sail, or by doubling the power of the engines in a steam-boat, a double velocity through the water will be obtained; but principle and experience will shew that a double power would hardly increase the velocity by half of what it was before. In practice, a quadruple power will not exactly produce a double motion, for the theory sup-

poses that the wind in the sails is increasing with the velocity of the ship, in order to keep up the same effect, and that in increasing the power of the engines, the resistance of the water to the float is the same, and that no more weight is added to the vessel; we know, however, that the latter conditions cannot take place, and the former only may at particular times. In general, therefore, a quadruple power will at most only produce a double velocity of the ship.

The effect of a fluid in motion against a plane at rest increases as the surface of the plane is enlarged, and it is also nearly the same thing whether the body is at rest, and the fluid in motion, or the fluid at rest and the body in motion; it is hence double upon a double surface, triple upon a triple surface, and so on. If we take the impulse of fluids to be as the duplicate ratio of the velocity, its impulse on one square foot of surface, at the velocity of one foot per second, is 48 ounces for salt water. Now, if we would determine the impulse on any surface moving with any velocity of feet per second, it will be expressed thus:—$a \times s \times v^2$, a being the resistance on one foot, s the given surface, and v^2 the square of the given velocity. The example may be given in figures; thus suppose the surface of a plane moving in a fluid is 4 square feet, and its velocity 10 feet per second; required, the resistance or force necessary to drive the plane at this rate?— $48 \times 4 = 192$, and $192 \times 10^2 = 19200$ ounces, or 1200 lbs.

The force of a fluid in motion is equal to the weight or pressure which produces that motion, *i. e.* the force which sets the fluid in motion is equivalent to the pressure or weight of a column of the fluid, whose base is the area of the plane, and its altitude equal to the height through which a body must fall to acquire the velocity of the fluid, which height is called the altitude due to the velocity. Now, if the body is to be opposed to a fluid of certain specific gravity, and moving with a certain velocity, if we put n for the specific gravity of the fluid, and using s and v as before; then $s \times n \times v^2 \div 2\,g$ or $s\,n\,v^2 \div 2\,g = R$, the resistance, or motive force required to move the plane with this velocity, or to sustain the plane against a current of the velocity expressed by v, g being $32\frac{1}{6}$ feet, which is the velocity of a falling body at the end of the first second of falling.

When the opposing surfaces are placed with different angles of obliquity to the current, the impression will be less than when the plane is at right angles to the direction of the fluid; and of a number of surfaces inclined in different degrees, it will be least on those that are most oblique to its course. Thus let A B (*Plate* V. *Fig.* 96) be a plane, perpendicular to the course of the fluid C A and D B; now this plane will receive the effort of the fluid contained between C A and D B. But if we take the same plane, and incline it as E B, it is evident that a portion of the particles contained between A F, which impinged on the plane A B, will miss it altogether—the number of particles which strike it in its oblique position, being to that when perpendicular as F B to A B. If we incline the plane still further, as to G, making it G B, the diminished action of the fluid will be expressed by the versed sine of the angle A B G, that is, as A H; or, the action of the fluid on planes placed with different angles will be directly as the right sines of these angles. But farther, it is well known that the fluid which exerts its force on the inclined surface G B or E B, does not produce the same impression as on the surface which is perpendicular to its course, as H B, be-

cause the direction of a particle of water which strikes any surface obliquely tends to carry that surface in two directions, one perpendicular, and the other parallel to the line of motion of the plane.

Before proceeding farther, let A B (*Plate* V. *Fig*. 97) be a plane moving in a fluid, in the direction D C; or let the plane be at rest and the fluid in motion, and its direction C D; then a particle C will move in the direction C D, and come in contact with the plane at the point D, and will thence incline to fly off in the direction of D E. The angle C D A or A D C is called the angle of incidence, and the angle B D E or E D B the angle of reflection, and is always equal to the angle of incidence, which is also sometimes called the angle of inclination, the one being equal to the other. Let A B (*Plate* V. *Fig*. 98) be a plane, acted upon by two powers whose force is respectively equal to the lines C D and G D; the direction of these forces is C D and G D. Now the effect of these two forces will push the plane A B in the direction D E, with a force equal to the line F D, which is the diagonal of the parallelogram erected on D C and D G; for if we now conceive the forces D C and D G to draw the plane A B, each in its direction D C and D G, it will be counteracted by applying a force on the other side equal to D F, in the direction D E; therefore, if the point D is acted upon by three forces, D G, D C, and D E, and D E be equal to D F, then the point D will have no tendency to move out of its place. Now let us see the force and direction of the impulse of a fluid on planes placed with different angles of obliquity to its course. We have shewn, that the quantity of a fluid which strikes an oblique plane decreases as the sine of elevation. When a plane is first placed perpendicularly, and then inclined to the current, the number of particles which impinge or strike the plane is relatively as 1 to *s*, which is the sine of the angle of inclination. The force of each particle will diminish with *s*; for it is evident, that as the angle of inclination of the plane A B is diminished, so will the sine of that angle be diminished, or so will the sine of incidence A D C be diminished, and with it the effect of the resistance arising from the impulse of the particles, which is as F D; for F D will continually diminish as the inclination of the plane A B (*Fig*. 96) diminishes, and will entirely vanish when A B is brought parallel with the line of motion D C, or direction of the current A E; for as there is no inclination from the parallel of motion, there is no angle of incidence, and of course no resistance to the longitudinal motion of the plane through the fluid, supposing the plane to possess no material thickness. We have shewn, 1*st*, that the number of particles of a fluid which strike a plane in an oblique direction, is to what would meet it if perpendicular to the current, as *s* to 1—conversely, as 1 to *s*, that is, as radius to the sine of the angle of incidence; 2*d*, that the force of each particle will diminish in the same ratio; hence the resistance to the plane in these positions, perpendicular and inclined, will be as 1^2 to s^2, that is, as the square of radius to the square of the sine of the angle of incidence. But farther, it must also be considered that this resistance is exerted in the direction D E (*See Fig*. 98), which is perpendicular to the plane itself. Now any force, in the direction D E, is to its effect in the direction of motion as A E to D E; this again is as radius to the sine of the angle of incidence, as 1 to *s*; therefore, for these three reasons, the resistance on a plane at right angles

to the direction of motion, is to that of an oblique plane as $1_2 \times a$ to $s_2 \times a$, *i. e.* the square of radius A B, multiplied by the area, to the square of the sine of the angle of incidence multiplied by the area. This would be true, if it could be proved that fluids attack bodies opposed to their motion in exactly the same manner as solids do. We have sufficient grounds, however, for thinking that the shock of a fluid is somewhat different from that of a solid, and therefore this theory is perhaps not exactly consistent with experiment; but from what has been said respecting the effort of a particle on an oblique surface, viz. that the effort of a particle at right angles to the surface is to the same in the direction of motion as F G to F B (*Fig.* 99); now F B is to F G as A B, the sine of the right angle, is to C B, the sine of the oblique angle of incidence; and it was before shewn, that the sum of the particles which strike A B is to the sum of the particles that strike B D, as radius is to the sine of the angle of incidence. Again, the effort of the water on A B is the effect of one particle, which is F B, by the number of particles, which are as A B; and the effort of the fluid upon B D is the effort of one particle F G, which we have shewn to be as C D multiplied by the number of particles, which is also as C D; therefore the effort of the whole fluid upon A B is to the effort of the whole fluid upon D B, as the square of radius is to the square of the sine of the angle of incidence F B D. Should the inclined surfaces be unequal, as A B and D B (*Fig.* 100), then the quantity of fluid which attacks them will be as their surfaces multiplied by the squares of the sines of the angles of incidence; hence the resistance to the perpendicular plane A B is to that upon D B, as the square of A B multiplied by the surface A B to the square of C B multiplied by the surface D B.

From what has been said on the resistance of fluids, the following corollaries may be deduced:—

1*st*, The retardation to the moving body is as the inertia or momentum of the resisting body.

2*d*, The resistance is as the squares of the velocity.

3*d*, The resistance to a plane perpendicular to the direction of motion, is as the area of that plane multiplied by the square of the velocity.

4*th*, The resistance to planes of the same surface, but placed with different angles to the direction of motion, will be to one another as the squares of the sines of the angle of incidence.

5*th*, The resistance to planes of unequal surfaces, and placed with different angles of inclination to the direction of motion, will be to one another as the squares of the sines of their angles of incidence multiplied by their surfaces.

6*th*, The resistance to planes of unequal surfaces, placed with different angles to the direction of motion, and moving with different velocities, will be to one another as the squares of the sines of their angles of incidence multiplied by their surfaces multiplied by the squares of their velocity.

7*th*, The resistance to a perpendicular plane is to the resistance of an inclined plane as the square of the radius, multiplied by the surface, multiplied by the square of the velocity of the perpendicular plane, to the square of the sine of the angle of incidence of the inclined plane multiplied by the area of the same multiplied by the square of the velocity.

It is unnecessary to illustrate by figures all these different cases. One example will be sufficient :—

Suppose the area of a square plane, placed at right angles to the direction of motion, to be 4 feet (24 inches on the side), let the velocity be 10 feet per second; then let it be required to determine the resistance to the same plane when placed at an angle of 60 degrees from the perpendicular position—the sine of the angle of incidence in this case is 12; and suppose the velocity of the inclined plane to be 13 feet per second. To proceed according to the 7th corollary, $24^2 = 576 \times 4$ surface $= 2304 \times 48$ ounces $= 110592 \times 100$ square of velocity $= 11059200 =$ proportional resistance to the perpendicular plane, and $12^2 = 144 \times 4 = 576 \times 48 = 27648 \times 13^2$ velocity $= 4672512 =$ the proportional resistance to the oblique plane. Now $11059200 \div 4672512 = 2.3$; hence the resistance of the perpendicular plane is to that of the oblique as 2.3 to 1; and as we know that the experimented resistance to a plane of 1 foot, with a velocity of 1 foot per second, placed at right angles to the motion, is 48 ounces, the question may easily be determined.

It may also be found thus—Call the square of the radius $\times$ by the surface $\times$ square of velocity the momenta of the perpendicular plane; and the square of the sine of the angle of incidence $\times$ the surface $\times$ the square of the velocity of the inclined plane, its momenta.

$$\text{Thus} \begin{cases} 24^2 = 576 \times 4 = 2304 \times 10^2 = 230400, \text{ momenta of perpendicular plane.} \\ 12^2 = 144 \times 4 = 576 \times 13^2 = 97344, \text{ momenta of oblique plane.} \end{cases}$$

Then as the momenta of the perpendicular plane is to its resistance, so is the momenta of the oblique plane to its resistance. 230400 : 12000 lbs. : : 97344 : 5070 lbs. the resistance of the oblique plane in lbs., and $12000 \div 5070 = 2.3$, as before.

The resistance of the inclined plane, in the above case, is to that of the perpendicular, in the ratio of 1 to 2.3. Now this is the advantage of sharpening out the bow of a vessel, so as to make it present as oblique a surface to the action of the fluid as other circumstances will permit; and we may, in a similar manner, compare the resistance to the bows of vessels of a greater or less midship section (that is, the greatest transverse breadth and depth.) We must observe, however, that as the water-line which forms the bow of a vessel is more or less curving, before we can determine the angle of incidence of the tapering of the bow, we must divide it into a number of parts. Thus, suppose A B C (*Plate* V. *Fig*. 101) to be the bow of a vessel whose midship ection or greatest breadth is A C; let D B X be the centre line, or line of the keel; also suppose we divide the water-line A H G F E B into portions, B E, E F, F G, &c., so that the portions B E, E F, &c. may be considered a straight line; then, to find the resistance on each of these portions, and finally on the whole—1*st*, find the sine of the angle I E B to any radius E B, then multiply it by the surface E B; 2*dly*, find the sine of the angle J F E with the same radius, multiply it by the surface F E; 3*dly*, find the sine of the angle K G F (always with the same radius), multiply it by the surface G F; 4*thly*, Find the sine of the angle L H G, multiply it by the surface H G; *lastly*, find the sine of the angle C A H, multiply it by the surface A H; add all these together, and double the sum, and you will have the effort of the fluid on the whole bow A B C,

which may be expressed by a. Then find the resistance of the midship frame A C, (that is, the resistance to a plane of the same area of the frame, and placed at right angles to the motion X B D); this is obtained by multiplying AC^2 by the surface, which is A C. Now we may express the resistance to the midship frame by b; and the resistance to the bow, or the advantage gained by making it in the form of A B C, is the product of $b \div a$; and it is evident that a will always be less than b, in proportion as the bow is carried farther out, and the angle of the water-lines is diminished accordingly. Suppose A D C to be the water-line of another vessel of the same midship section A C; then to determine the resistance to this bow, we must proceed as before. Let the portions of the water-line D M, M N, N O, O P, and P C, be considered straight; take the sine of all the angles Q M D, R N M, S O N, &c., as in the last case, and multiply them by the corresponding surfaces; add the products together, double them, and the sum will be the effort on the bow A D C; we may call this c. Hence the resistance on the two vessels is a and c, the one being to the other in the ratio of these quantities.

We have mentioned, that the resistance to ships having bows differently constructed may be calculated in this way; but there is an immense difference between the labour of merely considering the subject in this manner, and calculating the resistance on the bow of a real vessel. The bow of a vessel not only inclines in a horizontal or water-line direction, but also in a vertical and diagonal manner. We have considered it merely as a wedge, whose inclined surface is to split the water open; but a vessel of the most approved construction not only wedges the fluid asunder in a horizontal direction, but from the raking of the bow, she runs over it. The angles of incidence cannot therefore be given by the water-lines alone, as the fluid does not pass round the bow in a horizontal direction, but is deflected down under the bottom, by the raking of the bow; and from the degree of rake-out or fly-under of the fore part of the ship, the angle of incidence, as given by the water-lines, is about twice as great as they should be. In general, if the angle of incidence at any spot, as found by the water-lines to be 12, the true angle of incidence, in the direction of the action of the fluid, is about 6, or the one half, upon an average, of the whole bow.

It is possible, however, to find the angles of incidence with greater accuracy; and the operation is performed on what is called the plan of projection of the vessel. The whole fore part being divided into triangles, the angles of incidence of these and their surfaces are found, and are proceeded with as in the last example; the whole being added together, is then compared to the effort on the midship frame; and the same process being taken for different vessels, the approximation is considered fair on both, or in any comparisons that may be wanted.* M. Bouguer (a French author of great

* It is generally believed that the true action of the particles of the fluid on an opposing surface has never yet, and perhaps never will be discovered. How they are reflected or disposed of after impinging on the moving body, or whether they rebound, is unknown: Hence modifications of the resistance according to the form of the body cannot be accurately determined; for it is probable that the fore part of the bow of the vessel has an effect in disordering, by the motion of those particles which it has displaced, the fair action of the fluid on those parts which are behind it, so that the action on these parts will be different, and have a different effect from what they

mathematical learning), was, we believe, the first who applied the known laws of the resistance of fluids in this manner, to determine the comparative resistances to vessels, either proposed or built. The French are naturally fond of abstruse investigations, and they have carried the theory of manœuvring, as well as the theory of constructing ships, perhaps too far to be of any practical advantage. M. Duhamel du Monceau confesses, that if the ingenuity of Bouguer had not suggested the substitution of proportional lines in place of the squares of the sines of incidence, it would have been almost impracticable to reach the completion of the calculations by multiplying the surfaces of each triangle (into which the bow of the vessel is divided, which necessarily must be a very great number) by the square of its sine of incidence. But notwithstanding the assistance of these proportional lines, the operation is tedious, extremely abstruse, and does not enable us to ascertain the fact precisely. The effort of the fluid upon the bow of large war-vessels, such as 74-gun ships, is to what it would be on a plane equal to their greatest transverse section, in the ratio of 1 to $8\frac{1}{2}$ or 9; some more or less; small gun-brigs as 1 to 10. Some, indeed, are so fully built, that the effort on a plane equal to the area of their midship frame is only 4 or 5 times greater than that on the bow. At the same time, it is sometimes found, that although the effort on the bow to that on the midship frame is not diminished in so great a proportion in one vessel as another, yet she that had it diminished least, might be equally swift with the other; because, if her midship frame has a less area than the others, she will have a less resistance, arising from the number of particles of the fluid which must be displaced; but if the area of both their midship frames be equal, then this could not be expected, and she would in all probability be the slower sailer of the two. It is unnecessary to say more at present on this subject, except to observe that there are many other things to be considered in the construction of a vessel for fast sailing, as well as the tapering of the bow. The due proportioning of the runs (or stern end) to the bow or entrance has no doubt almost as much effect on the sailing of the ship as the sharpness of the bow itself. We shall consider these things afterwards, and shew those forms of the body of ships which a long experience has proved to be the most proper.

The velocity of feet per second, which is agreeable to different rates of velocity of nautical miles per hour, is as follows:—

Velocity in Feet per Second.		Nautical Miles per Hour.	Velocity in Feet per Second.		Nautical Miles per Hour.
1.6909	is equal to	1	8.4548	is equal to	5
3.3819	,,	2	10.1456	,,	6
5.0728	,,	3	11.8360	,,	7
6.7638	,,	4	13.5275	,,	8

Fig. 102, *Plate* V, shews the resistances to the opposite bodies, as found by experiment made in the year 1797:—

would have were they separate from the action of the same particles which had acted on the parts before them. The theory, however, considers that the action will be the same as if the after parts were detached and exposed with the same inclination to the fluid.

Nautical miles per hour,		1	2	3	4	5	6	7	8
The same cylinder and semi-globe on the stern end,	Resistance,	2.34	9.96	22.96	41.33	56.04	94.06	128.37	167.97
Do. do. and semi-globe on the head end,	Resistance,	0.93	3.70	8.22	14.43	22.28	31.73	42.76	55.34
Do. do. do. on each end,	Resistance,	0.75	3.03	6.78	11.96	18.53	26.45	35.71	46.29
Globe,	Resistance,	0.88	3.85	8.91	16.05	25.24	36.45	49.66	64.87

The French, and the Society for the Improvement of Naval Architecture in London, have made many expensive experiments, in order to discover the laws of the resistance of fluids to bodies, but with very slight success. They have ascertained that the present theories are incorrect, and that those bodies which resemble the bottoms of well-constructed vessels suffer the least resistance. It has been found that the resistance does not in every case follow the law of the square of the velocity—neither the law of the sine of the angle of incidence—neither exactly as the surfaces, the position and velocity being the same.

As it is inconsistent with the plan of this work to enter into any investigation of elaborate theories, we beg leave to refer those who are fond of such pursuits to the Report of the Committee for conducting the Experiments of the Society for the Improvement of Naval Architecture—to Steel's work on the same subject, which contains a considerable part of their report—and to works on natural philosophy.

As we must employ some of the terms used in the theories of resistance when considering the sailing motion of ships, it will be proper to define them.

1*st*, *Capacity*.—By this is meant the mass or quantity of matter in the whole vessel, and this is always in proportion to her length, breadth, and depth.

2*d*, *Stability*.—By this is meant the stiffness or power which the vessel has to return to her upright position, or to oppose any force tending to incline or heel her in any manner; and this stability is always in proportion to the capacity, if the form of the vessel be the same.

3*d*, *Resistance* is an obstruction to the movement of the body, as before explained. The resistance of a fluid to a moving body is equal to the power which moves the body with a given velocity. A body immersed in a fluid is pressed upon all sides with a force proportional to the depth below the surface of the water. If a body be immersed in a fluid, it suffers a pressure on its head end, which prevents it from moving forward; this pressure is called the head pressure. It also sustains a pressure on the other end, called the stern pressure. If the body be moved forward, it sustains an additional pressure, caused by the fluid being removed out of its place, to allow the body to pass. This pressure is called the plus pressure; and the subtraction of pressure from the stern, occasioned by the fluid not pressing so strongly against the stern end when the body is moved forward, as when it is at rest, is called the minus pressure. There is yet another obstruction to the movement of the body, *i. e.* the friction arising from the adhesion of the particles of the fluid to the sides and surfaces of the body. Hence, by the term resistance, is meant the retardation which the water makes to the movement of the body, arising from one and all of these causes combined.

4*th, Vis Insita*, or *Inertia*, is a property of matter, and, as applied to the motion or state of rest in a ship, is the power by which she endeavours to persevere in that state, whether of rest or of moving uniformly forward in a right line.

When a body moves along the surface of a fluid, the surface is elevated towards the fore parts, and depressed behind; and these elevations and depressions are in proportion as the ends of the body are more or less obtuse. The body itself is the more retarded on this account. The greater the irregularity of the motion of the fluid, the greater is the resistance which it presents to the motion of the body. From these effects it therefore follows, that the grand point in constructing a body intended to move swiftly through the fluid, is to give it that form which will allow it to move smoothly, without producing extreme agitation in the particles immediately in its course, and in the vicinity of the moving body. But what is the exact form of this body, or its curvature, when of a given dimension, has not been proved experimentally.

On the Discharge of Fluids

Through Apertures in the Bottoms and Sides of Vessels.

If a fluid flow through an orifice into an empty vessel immersed in the fluid (or from a vessel into the air), and if the vessel immersed in which the fluid is flowing be prevented from sinking deeper, or be filled up to the orifice,—or if the surface of the fluid in the vessel from which it is flowing be kept at the same height, the velocity of the fluid through the orifice will be equal to that which a body would acquire in falling freely through the height of the fluid above the orifice, which is eight times the square root of the height, according to the laws of falling bodies.

The velocities (or quantities discharged) at different depths are as the square roots of these depths, *i. e.* the velocity of the fluid, corresponding to any given height, is to the square root of that height, as the velocity of the same fluid but of a greater or less height above the orifice, is to the square root of its height; and the quantity which will flow through the orifice in a given time is as the area of the orifice and the velocity, and this is evidently equal to a cylinder or prism, whose base is the area of the orifice, and its altitude the space described by the velocity acquired in falling through the height of the fluid above the orifice; so that if h denote the height of the fluid above the centre of the orifice, a the area of the orifice, g $32\frac{1}{6}$ feet, or 386 inches, the velocity of a falling body at the end of the first second, and t the time in seconds, we shall have the quantity discharged, $Q = a \times t \times \surd 2gh$. When a and h are given in feet, we shall have $Q = 8 \times a \times t \times \surd h$; this will give the quantity in feet, which being divided by the number of feet that make a ton (35) will give the answer in tons.

As water presses equally in every direction, it is easy to conceive that it will spout or flow through an orifice with the same velocity whether it be upwards or downwards or horizontally; its force is hence the quantity multiplied by the velocity. But the quantity discharged in a given time is as the velocity; therefore its force is as the squares of the velocity.

The following is a table of the velocities with which water flows through an orifice

below the surface, according as it deepens under the same. It will shew that a very small hole in the bottom of a vessel will admit much more water than one which may be larger, but near the surface; this may teach us that very great care should be taken to secure and tighten the bottom of the ship properly.

Depth in Feet.	Velocity in Feet, per Second.	Depth in Feet.	Velocity in Feet, per Second.	Depth in Feet.	Velocity in Feet, per Second.	Depth in Feet.	Velocity in Feet, per Second.
1	8.02	7	21.21	13	28.91	19	34.95
2	11.34	8	22.68	14	30.00	20	35.86
3	13.89	9	24.05	15	31.05	21	36.64
4	16.04	10	25.31	16	32.07	22	37.52
5	17.93	11	26.59	17	33.06	23	38.32
6	19.64	12	27.77	18	34.02	24	39.12

With respect to the accuracy of the theory of the discharge of fluids, it may be observed, that owing to the attraction of the particles which issue out near the edges of the aperture, (on which account they suffer more retardation than those which issue through the centre of the aperture), the mean velocity will scarcely amount to what is given in the table.

Sir Isaac Newton discovered a contraction in the vein of a stream, which issues out through an orifice; and he found that, about the distance of a diameter of the orifice, the section of the stream contracted nearly in the subduplicate ratio of 2 to 1. From this he concluded that the velocity of the water after its exit from the aperture was increased in the same proportion, the same quantity passing through a smaller space in the same time; but he found that its velocity there was only that which a body would require in falling through the height of the fluid above the orifice.

The contraction of the vein, immediately after it has left the aperture, takes place at a greater distance under strong charges, than in those which have but small elevation. This contraction of the stream is accounted for by supposing that the filaments which are nearer the centre, move faster than those which are near the edges, and that its diameter is diminished to a certain extent, because the exterior particles are gradually drawn, in consequence of their mutual attraction, by the interior filaments, whose velocity is greater than those which are near the sides of the orifice; at the distance of about half its diameter, the stream is supposed to be 4-5ths of the diameter of the orifice; therefore the quantity discharged will fall short of what is given in the above formula. Hence, in place of multiplying the square root of the height by 8, if we multiply by 6.5, we shall come nearer the true discharge.

On Pumps.

Before concluding our introductory remarks, I shall lay before the reader a description of the common hydraulic engines employed in raising water from one level to another; and also an account of a double-working pump, which has been very much approved of by scientific men, shipmasters, and others familiar with such machines.

By means of the lifting and forcing pump, water may be raised to almost any height, with a sufficient power and proper apparatus; but by the sucking pump, water cannot

be raised higher than 33 feet; for in it the water in the barrel is not raised or lifted up this height by the boxes, as in the lifting pump, but by the pressure of the atmosphere on the surface of the water in the well. The height which water can be raised by the sucking pump is limited to about 30 or 33 feet. In practice, water is seldom raised higher by this pump than 28 feet perpendicularly. This arises from the variation in the weight of the atmosphere, which is sometimes less than the weight of a column of water of 33 feet in perpendicular height; when this is the case (for want of a counterpoising weight), the water will not rise so high as 33 feet; and if, at this time, the distance between the water in the well and the working-box of the pump be greater than the height of the column of water which the atmosphere would support in the vacuum of the pump, the pump would fail in its performance. A description of the common sucking pump will explain how this takes place. The common sucking pump consists, first, of a pipe of wood or metal, of 3, 4, 5, 6, or any number of inches in diameter, and of an appropriate length, according to the circumstances of the place in which it is to be wrought; this tube is open at both ends, and has a fixed valve opening upwards, placed in about 1-3d of its length; it has also a moveable valve opening upwards (these valves are called boxes or buckets), which is moved up and down in the barrel of the pump. The part in which the box works is called the chamber of the pump; the boxes are made to fit the bore of the pump exactly, that is, of the chamber, and they are leathered all round, so as to fit it the more closely, thereby preventing the air from passing down by its edges. The first operation is to exhaust the air in the pump. The valve is in the centre of the box, and this valve, or clapper as it is sometimes called, consists of a piece of leather, with a piece of hard wood or lead on its upper side. The moveable box is worked up and down in the chamber of the pump, by being attached to a short rod of iron connected with the end of the handle or pump-break. The fixed box is commonly placed in the barrel, a little below the greatest descent of the working-box. The operation of working the pump is very obvious: when the handle or break is depressed by the hand, then the other end is raised up, and with it the bucket; as no air can get down from above the box, a partial vacuum is formed between the two boxes in the pump, and as this destroys the equilibrium which existed between the air above the fixed box and that below it, or as the air between the two boxes will now be rarified, by being expanded into a greater space, the air in the lower part of the pump will force open the valve in the lower box, and rush up into the chamber of the pump, by which means the equilibrium will be again established; but upon the upper box being depressed, the valve in the lower box will be immediately shut, and the valve in the upper will open; then, on drawing it up, the air in the chamber will be again rarified, and so on—the water, at the same time, beginning to rise in the bottom of the pump; and as you go on to exhaust the air in the pump until you have a vacuum, the water will rise and pass up through the valve of the lower box. While the upper box is exhausting the air from the pump, the water is rising, and the weight of this column of water, together with the weight of the air remaining in the pump, will, in every stage of the ascent of the water, be exactly equal to the weight of the atmosphere pressing on the surface of the water in the well.

When the water has risen to the height of the lower box, and the upper box is drawn up, the water will rise up and follow it; then, when the box is again depressed, the valve of the lower box immediately shuts, while that of the upper one is opened by the water passing up through the box as it descends. Now, when the box has attained its greatest descent, all the water which before was between the two boxes, is now above the upper box, whose valve is shut; and when this box is again raised up, of course it brings up before it the length of its stroke of a column of water, which is discharged at the nozel of the pump; the box is again depressed and drawn up. By every stroke of the handle the same effect takes place; and it will easily be seen, that no water is raised up whilst the box is descending in the barrel. The discharge at the nozel will not be in a constant uniform stream, but in jets, &c.

The Lifting Pump.—This pump differs very little from the sucking pump; the water is lifted much higher above the working-box before it is discharged. It is used in deep mines; and it may be necessary to notice, that it is of no consequence whether the working-box be placed at 28 feet from the surface of the water in the well, or at any less distance; for the weight of water to be raised will still be the same.

The Forcing Pump.—In this, the water is raised through the lower box, as in the other two; but the upper box has no valve in it, being a solid piece of wood or metal, which is called the plunger. After the water has risen above the lower box, it cannot get above the plunger when it is pushed down into the chamber, but is forced up by a conducting pipe, *i. e.* a pipe which branches of from the chamber of the pump above the fixed box. A valve is fixed in this pipe, which prevents the water from returning back into the main pump, when the plunger begins to rise again; and upon raising and depressing the plunger, the water will first flow up through the lower box, the valve of which will immediately close, and as the plunger descends, the valve in the conducting pipe will immediately open, and the water will be forced up through the conducting pipe to the required height; but it will come out with jets, as in the other two pumps. In order to procure a nearly uniform stream of water from the mouth of the conducting pipe, its mouth is made much less in diameter than the barrel of the pump, and there is added an air-vessel, in which air is strongly compressed by the force of the water which is thrown into the air-vessel by the pump; and from this air-vessel the small conducting pipe is taken. The air being strongly compressed by the water, it reacts on the surface of the water in the vessel, and by its elasticity keeps a constant pressure on the same, and thus causes an almost constant flow of water from the mouth of the conducting pipe; but the pump throws no more water than the common lifting pump. The machines called fire-engines are constructed on this principle: they have two force-pumps; the water from the cistern is thrown with great force into the air-vessel, and from the pressure of the air in the same, it is thence discharged with great force, and to a considerable distance, from the mouth of the conducting pipe.

The Chain Pump.—In order to understand this pump more thoroughly, see *Plate* IX. *Fig.* 1, which represents a section of a chain pump. A B is the barrel, C is the end of a drum or wheel at the top, and D the same at the bottom of the pump. These drums are made to turn on an axle, passing through a wooden or iron standard, which

is firmly bolted or hooped to the barrel; an endless chain of a particular form, having pistons, circular or square according to the form of the barrel of the pump, for sometimes it is made square. These are fixed at proper distances from each other; the chain, with its string of pistons, is passed up through the barrel and over the drums or wheels at the ends of the pump; the iron rods, which form the sides of the drum or the teeth of the wheels, are placed so as to catch the chain at the joints, and to let the pistons fold in between them. There is also another set of rods or teeth on the drum or wheel, which catch a small stud or projection on the edges of the double links of the chain. The effect of this is, that it relieves the strain on the joints of the chain at the moment of their turning over the panes of the wheel or drum, and thereby lessens the friction. There are many different ways of constructing the chain-pump, and of applying the power to work it. Sometimes a barrel is added to receive the descending buckets, and the motion or power is increased by wheels and pinions, according to the quantity of power which can be employed to work the pump. If the wheel or drum C be made to revolve in the direction of the arrow, the chain and pistons will also be put in motion; consequently a whole row of pistons will be rising in the pump barrel, while the other half is descending. The lower end of the pump barrel must be immersed in the water at least equal to the distance between the pistons, in order that the pump may work up to its proper effect. This would not be required, if the pistons fitted the barrel so exactly as to produce a complete vacuum in it, but the pistons are commonly made of a smaller diameter than the bore of the pump barrel by about 1-8th of an inch or so; this reduces the friction considerably, and when the pump is worked smartly, and a column of water is thereby set in motion, little or none can descend by the sides of the pistons. From the pistons being alternately turned over, any thing that would tend to destroy the operation of the common pump is thrown out, and on this account the chain pump is often used for draining marches, sewers, &c.

The great friction on the axles, and that caused by the links of the chain, the great space which it takes up in the vessel, and its expense, are obstacles to its being more generally used, which cannot be obviated.

Description of the Double-Working Pump.—(See *Plate* IX.)

I shall now proceed to a description of the Double-working Pump, of which the remaining figures in *Plate* IX. are the various sections. They have been drawn to a proper working scale.

Before doing this, I have a few remarks to make connected with this subject. I regret that sailors do not possess more knowledge of the principles and construction of pumps, and that shipowners and captains in many instances are so indifferent as to this part of the outfit of their vessels. There are few examples of extravagance in this respect, though no expense is spared in the other departments. Although the principles on which the common pump is constructed are understood by every skilful mechanic, it is somewhat remarkable, that amidst the vast numbers of mechanical improvements which have been laid before the public within the last twenty years, there has been none of any consequence on pumps, with the exception of the double-working pump.

I shall not stop to notice the alterations which have been made in constructing valves for common pumps, &c. The following is an outline of the circumstances that led to the invention of the double-working pump. In 1796, I was on a voyage in a very leaky vessel—being chief carpenter, the charge of the pumps devolved on me. In crossing the north sea, our vessel made so much water that the crew were continually at the pumps. I was induced, therefore, to attempt to construct a pump which might draw twice as much water as an ordinary one, and occupy no more room in the vessel. I carried my invention into effect, a model was made on a small scale, and on trial, it was found to draw double the quantity of water which an ordinary pump did. When on an extended scale, it drew nearly as much water as a chain pump of the same diameter of pistons, and required only half the power to work it. It possessed this advantage, that it admitted of being taken to pieces, and stowed away in any secure part of the vessel,—for instance, during an engagement, and could be put up again in three minutes. I was so sanguine as to suppose that a knowledge of its advantages would have led to its adoption by the commercial interests of the United Kingdom. In 1813 or 1814, I laid a statement of this improvement before the Surveyors of the Navy, in whose presence the advantage that the double-working possessed over the common pump, was completely proved. It was also highly approved of and recommended by Admirals Hope, Hunter, Otway, and others. I had reason to believe, however, that no improvement would be recognised by the Surveyors, unless it originated with themselves; and they latterly resolved, that the double-working pump could not be used with advantage in the Navy. The Edinburgh, Glasgow, Leith, and London Shipping Company, sensible of the advantage to be derived from this pump, ordered one to be fitted on board the Eagle, one of their smacks which sail between Leith and London. The Captain of this vessel has used it since the year 1815, and has had many opportunities of observing its superiority over the ordinary pump.

When I found that the Surveyors were unchangeable in their opinion, I laid the plans and model of my newly-invented pump before the Society of Arts, Commerce, &c., as I flattered myself that there was a greater probability of obtaining a candid opinion from a Society institued for the promotion of the Arts, than from the Government Surveyors. My expectations were realized; and on an investigation into its practical advantages, the Society expressed their opinion of the great utility of my double-working pump, by awarding me twenty guineas and a silver medal. An attempt was made to convince them that a similar kind of pump had been tried in the Navy, and had proved abortive; but the committee, on investigation, scouted the attempt altogether.

It may appear singular that an invention of so much practical advantage has not been more generally known. The surprise will vanish, when the reader is informed that the expense of the double-working pump is a little more than that of an ordinary one. The insurance companies require two pumps in every vessel that they insure. The blockmaker has no interest in recommending the double-working pump, having more profit in making two pumps than one.

The merit of the double-working pump consists in both the boxes being moveable,

and hung or suspended from the pump-rods on a true mechanical principle. They are made to work up and down alternately by the most simple and plain construction of the breaks, &c., thereby producing a constant and uniform stream of water, the one box being constantly ascending, while the other is descending. *Fig.* 2 is a section of the pump as fitted on board the Eagle Leith and London smack. A B is the chamber, or working-barrel; B C the suction-pipe; A D cisterns at the top; D E and F G are iron standards, which ship into staples on the inside of the cistern—these standards are made with a notch at the parts E and G, to receive the breaks G H and E I; *b* and *c* is the pivot on which the breaks work; and the pieces *b c* on each side are for steadying the tops of the standards, the bolts *b c* being merely common pump-bolts passing through to the other side, and are prevented from working out by means of a forelock, as in the common pump. E J and G K are part of the breaks, fixed at right angles with the handle in form of a bell-crank, and they must be sufficiently strong to bear the weight of the water contained in the pump, if only one handle is employed; J K is a connecting-rod for regulating the motions of the boxes. We have drawn this pump with two handles or breaks; but it will appear obvious on inspection, that from the intervention of the connecting-rods, any one of them might be cut off by the head of the standards, as at G or E, and that, in raising the handle at I, the other end of the break at L would be descending; and as the crank J X is fixed firmly into the break, it of course would be carried towards the left side of the pump, and the connecting-rod J K would at the same time push the crank K towards the left, which would in its turn raise the break M; and always as the break E I is raised and depressed, the points L and M will be working alternately in the opposite direction to each other. L O is the spear of the lower box, passing down through the centre of the upper one; it is attached to the break and box in the common way, but has a joint at P for the purpose of allowing the lower part, which passes through the upper box, to slide up and down in a vertical direction, the bridge of the upper box serving the purpose of a parallel motion. M Q is the spear of the upper box, jointed at Q, and both their spears are bridled, as shewn by *Fig.* 3, which is a section at right angles to section *Fig.* 2. As the spear of the lower box passes down through the centre of the upper one, it is made with a loose scarf or socket-joint, so as to be easily united to the upper parts. The lower ends are fixed in the sides of the box with prongs in the usual manner; and both spears are made of such a length, that the lower box will be once and a half the length of the greatest stroke below the upper one, when the breaks are placed in a level position. The whole apparatus being thus completed, the boxes are put in motion by working the handles at H and I, the one always ascending while the other is descending. A constant and uniform stream of water is discharged from the mouth of the pump, more than equal to what would be produced by two pumps of the common kind, of the same diameter in the chamber, and driven with the same power. It may be thought singular how it can possibly raise more than double the quantity of water that the common pump does. The reason, however, is obvious, when we consider that in the common pump the column of water is stopped and set in motion alternately, and the power required to do so is greater than what would keep the same column of water in a continued motion. In the double-working

pump, the reverse of this is the case, for in it the column of water is not so stopped and set in motion again, but is continually accelerating as we continue to increase the speed of the boxes, but in a greater ratio, until it has acquired its maximum velocity, and a momentum which *would even continue the motion* were the power withdrawn for a moment; and as it is a well-known law in mechanics that it is much easier to keep up motion after it is first produced, than to stop it and produce it alternately, the performance of this pump is nothing more than what the principles on which it depends would lead us to expect. Also we *have an advantage in a double action* with only one opening and shutting of the valves.

Fig. 4 represents sections, shewing a method of double-working two pumps, producing an effect equal to four pumps of the same diameter in the bore, on the common construction. The horizontal black line, extending from one end of the plate to the other, represents the deck; *Fig.* 4 is a section of *Fig.* 5, taken at right angles to the plane of the paper. This pump was drawn for a Greenland ship, and would be found of great service in any large vessel. A B, A B (*Fig.* 5) represent the two barrels cut up the middle, with their boxes left whole; and A B (*Fig.* 4) is a section of the same, shewing the position of the joints of the spears, &c. In this section, the boxes are cut through the centre. C D (*Fig.* 5) is the working breaks or handles moveable on the journal G, and having two pieces, E F and E F, fixed at right angles to its length. This kind of handle is of great advantage, as a number of men can work with the same leverage power. On the under side of the break is fixed the toothed quadrant G H, (the same letters are used for the same parts in *Fig.* 4.) On the same vertical line, passing through the centre G, is fixed, at a proper pitch, another toothed quadrant H I, having two arms radiating from the centre I J and I K, with turned joints at I and K, to which the pump-rods are attached; J L and K L are the spears of the lower boxes M M. Thus the spears of the lower boxes are attached to the break J K, the spears of the upper boxes are attached to the breaks C D at the centres N and N; and N O are the spears of the upper boxes P P. Now, for the operation of working the pumps, we will suppose that the handle C D is descending at C, and rising at D; and according to the manner in which we have shewn the boxes, the upper one, in the one pump, with its clappers and valves raised, and the lower one in the other pump, with its valves raised, must have already moved down the chambers 2 or 3 inches. We will then suppose the handle at C to be descending, and as a necessary consequence, the box P in the one pump also descending, while at the same time the box P in the other is ascending; but at the same instant the quadrant G H has been acting upon H I, and causing it to move in the reverse direction, thereby raising the break or crank J, and depressing K, thereby raising the lower box in the one barrel, and at the same instant depressing the other; and so on continually as the break is worked up and down, which will appear obvious from a minute inspection of the figure, as will also the construction of the bridles and joints of the spears, from an inspection of *Figs.* 4 and 6.

Fig. 7 is a plan of the upper box, and *Fig.* 6 a section of the same, shewing the spear of the lower box passing down through its centre; these I have thought proper to draw on a large scale, that their parts might be the better understood.

The upper box is fitted with two small pieces of metal, A B and C D (*Fig.* 6) crossing the centre; the lower one is made in a triangular form, and is let down in the sides of the box, till it is flush with the upper part—it requires to be of sufficient strength to answer for a bridge for supporting the clappers; the upper piece A B is merely for holding down the leather of the clappers, and is made no thicker than is necessary for that purpose. Both of these pieces have a hole in the centre for the spear of the lower box passing down through; the screws shewn in the section are for screwing down the upper piece and the leather of the clappers, which form their hinges, to the lower bridge C D. The joints and other parts, with their respective dimensions, will be sufficiently pointed out in the following direction for constructing a double-working pump. We may observe, in concluding this description of the double-working pump, that its expense only amounts of about 5-8ths of the expense of two pumps on the common construction, to draw the same quantity of water.

To erect a Double-working Pump of a proper size for a ship of 200 tons, to be wrought by the power of four men—the height to be 16 feet from the surface of the water to the place of discharge.

Let the dimensions be as under:—The working-barrel 7 inches in diameter, and its length 3 feet 8 inches; the diameter of the suction-pipe 4 or 4½ inches; the distance between the centre of the crutch and spear holes in the break 9 inches; the distance between the centre of the crutch hole and the cross handle 3 feet 8 inches; and the diameter of the discharging pipe 5 inches; the cistern 11½ inches wide and 14½ inches deep, inside measure; the under side of the discharging pipe to be 2 inches from the bottom of the cistern, and the top of the cistern to be 1 foot 6 inches above the deck, being rested on commons 2⅛ or 2 inches high. The two iron standards and double-headed iron breaks, and connecting rod, with a stretcher to keep the standards a proper distance, as shewn in the plan. The top of the standards to be 2 feet 6 inches above the cistern, and the bolt-holes 3 feet 9 inches above the deck.

The dimensions of the spears of the upper box are—

	Feet.	Inches.
The centre of the lower joint, from the top of the box, ...	0	6¼
To the top of the spears, ...	3	3¼
To the centre of the working bolt, ...	0	7½
Whole length of the spear from the top of the box to centre of the bolt, ...	4	5

And the dimensions of the spears of the lower box—

	Feet.	Inches.
Inside height of the prongs, ...	0	4⅜
Length of the socket, ...	0	2¼
Do. to the centre of the pendulum joint, ...	2	8
	3	2⅞

	Feet.	Inches.		
Length to the top of the opening of the sheers, ...	1	6	2	11
Do. to the centre of the working bolt, ...	1	5		
Whole length of the spear, from the box to the centre of the bolt,...............			6	1⅞

MARINE ARCHITECTURE,

PART II.

CHAPTER I.

CONTAINING

AN EXPLANATION OF THE TERMS USED IN SHIPBUILDING; OBSERVATIONS ON THE SAILING, ROLLING, AND PITCHING MOTIONS; GENERAL PROPORTIONS OF LENGTH, BREADTH, AND DEPTH OF MERCHANT SHIPS; ILLUSTRATIONS OF THE PRINCIPAL LINES AND SECTIONS USED IN DRAWING OUT THE WORKING PLANS OF VESSELS.

Marine Architecture may be considered the art of designing, planning, and constructing all sorts of machines connected with the sea, such as ships or vessels, harbours, with piers, wet docks, slips, embankments, &c. That part of Marine Architecture more immediately connected with the construction of ships of war, may properly be called Naval Architecture. That which relates to the formation of harbours, &c. is generally comprehended under the science of Engineering. The former is executed by persons called Naval Architects, Marine Engineers, or Shipbuilders,—the latter by those called Civil Engineers.

In the following pages I propose to treat of the theory and practice of Shipbuilding as applied to the construction of vessels, not for the purposes of war, but for the conveyance of goods or merchandise from one port to another. Although the fundamental principles on which these two classes of shipping are constructed are the same, yet as the purposes for which they are intended are different, a different construction is absolutely necessary.

In the theory of Marine Architecture, I shall consider the properties and action of ships generally, their different forms, and give instructions for delineating their working plans and sections; and in the practical part of our work will be found directions for the proper execution of these plans, and the actual building of merchant vessels.

Of the Principal Divisions of the Hull.

Before noticing the alphabetical arrangement of the terms used in this treatise on shipbuilding, let us first notice the principal divisions of the Hull, that is, the names that are given to particular parts of the vessel, not including the names of the timbers, &c. which form these parts.

The principal dimensions of a ship are her length, breadth, and depth; and from these three dimensions the tonnage or burden of the vessel is computed. Let *Fig.* 103, *Plate* V. represent a vessel; A is the bow, and S the stern end. Suppose the line which joins A S to be the surface of the water when the ship is immersed; now all that part of the vessel under this line is called the bottom, *i. e.* all that is immersed in the water; and all above the line A S is called the upper works of the vessel. The bottom and upper works taken together are called the hull; but the word Ship includes the hull, together with the masts, sails, rigging, &c. &c. The hull of the vessel is also divided into two great divisions by the perpendicular line marked ⊕; that half or portion A B E M, above and below water, and which is before the perpendicular line ⊕, is called the fore body; and that part of the hull S Q R M, above and below water, and which is abaft the perpendicular line ⊕, is called the after body. Now, suppose the length of the vessel on the water-line A S to be divided into eight equal parts, as 1, 2, 3, 4, &c.; let a perpendicular line be drawn through the second division from the bow, and another through the third division from the stern: the vessel will then be divided into three parts by these lines. The part E, before the foremost perpendicular line in the figure, and below the water-line A S, is called the entrance; the part B before the said perpendicular, and above water, is called the bow, and it extends to two-eighths of the length of the vessel from the fore part of the stem. The middle division, contained between the two perpendiculars, is called the midship body, both as regards the bottom and upper works, and it contains three-eighths of the length of the vessel. The remaining part, marked R, abaft the after perpendicular, and under the water-line, is called the run, and it contains three-eighths of the ship's length. The upper-works above the run marked Q are called the quarters; the line $b\,g\,g'$, represents the lower edge of what is called the main wales; the part $b\ c$ is called the counter, and $c\ d$ the stern; that part of the runs at the letter b is called the buttocks; the line $e\ e'\ e''$ marks the top of the ship's side, and is called the top-height or sheer-line, or main gunwale; $f\,f$ is the rail; and when the vessel is boarded up from the line $e\ e'$ to the rail, she is said to have bulwarks.

The figure represents two dimensions of the ship, viz. the length and depth; and it shews the form of the vessel agreeable to these two dimensions, but not with respect to her breadth. Therefore, to give some idea of the shape and form with regard to the breadth, we shall employ figure 104. The large figure represents the size and shape of the vessel. Supposing her to be cut or sawn horizontally from stem to stern, the portion E is the entrance, M the midship body, and R the runs; A h is the curve of the entrance; $h\ g'$ that of the midship body; and $g'\ b\ s$ that of the runs. Some idea of the shape of the vessel in a vertical and cross direction, *i e.* in the direction $i\ j$, may be formed by inspecting the three lower figures. That marked ⊕ is the greatest transverse section in the whole ship—it is called the midship section; E is a section of the entrance, and R a section of the runs; the part J is called the bilge.

Having thus given the reader some idea of the form and names of the principal parts of the hull of the vessel, he will the more easily recollect the names of the different timbers which compose these parts, as they are taken chiefly from those parts of

the vessel in which they are situated; as, for example, a bow-timber signifies a timber which is to be placed on the bow; quarter-timbers, stern-timbers, and so on, according to their respective places in the ship.

Definition of the Principal Terms used in the Theory and Practice of Shipbuilding.

Abaft or *Aft*, toward the stern or hinder part of a ship.
After-body, every part of the hull of the ship which is abaft the midship section.
After-end, the end of any piece of wood which is nearest the stern of the ship.
Aboard, *on board*, any thing in, or on the deck of the ship.
Afloat, buoyed up by the water.
Afore, the fore part, towards the bow of the ship.
After, the after part, towards the stern.
Ahead, before the bow of the vessel; *astern* is the opposite term.
Amidships, the middle of the ship.
Anchor-stock, two pieces of wood bolted together on the shank of the anchor.
An-end, to strike any piece of wood, so as to drive it in its length direction.
Apron, a piece of wood bolted on the inside of the main stem, to strengthen and fasten it to the keel.
Archboard, a plank of the stern, on which the name of the ship is commonly painted.

Balance-frame, a frame or timber formed at a certain part of the ship, corresponding to another frame at a different place. There are generally two balance-frames used in the plan, the one in the run and the other in the entrance; these being nearly similar in shape, and placed in opposite parts of the ship, serve to balance the bottom, as all the other frames are regulated by them and the position in which they are placed.
Ballast, any heavy material, such as sand, stones, or iron, &c. placed in the bottom of the vessel, to lower the centre of gravity and make the vessel stable, so as not to be easily canted or heeled over by the impulse of the winds or waves.
Barge, a kind of pleasure-boat, constructed either for sailing or rowing with oars.
Bark, a square-rigged vessel having three masts, but without having a mizen-topsail.
Barrel, the main piece of the capstan or windlass, about which the rope or cable is wound.
Battens, long narrow slips of fir, used for fairing or sheering the ship, or drawing the lines by in the moulding loft. A batten commonly signifies a long narrow slip of wood.
Beams, large pieces of timber extending from the one side of the vessel to the other, for binding her together and supporting the deck. The midship-beam is the beam immediately at the midship-frame.
Beam-line, a line made on the inside of the timbers at the height of the decks, for laying the ends of the beams fair.
Bearding-line, a line drawn on the dead-woods.
Belfry, an ornamental frame fixed over the windlass, or near the bow, on which the bell is hung.
Belly of a Timber, is the inside of its curve.
Bends, a general term for the main-wales. These are thick planks put round the outside of the vessel.

Bends, sometimes mean the curving timbers, or the frames: thus the midship-frame is sometimes called the midship-bend.

Bevellings are the different angles or twistings of the edges of the timbers or planks. When the edge of a timber forms an obtuse angle with its side, it is said to have a standing bevel; and if it form an acute angle with the same side, it is said to be an under bevel.

Bilge, the outer part of a ship's bottom, on which she rests when aground.

Bilge-pieces, planks or keels fastened on the bilge of the vessel, for strengthening that part which rests on the ground. Bilge-keels are sometimes put on the bottom, running in the same direction as the plank, that is, in a fore-and-aft direction, to prevent the vessel from heavy rolling, or from drifting to leeward, or the like.

Bilge-wayes, *bilge-coads*, or *sliding baulks*, large square logs of timber placed under the bilge of the ship, to support her on the sliders or sliding planks on which the vessel is launched.

Bindings, pieces of wood or iron which bind or fasten the vessel together.

Bitts, any pieces of timber for supporting the windlass, or for making the hawsers or cables fast to them. The riding-bitts are those to which the cable is fastened when the vessel is at anchor. The pawl-bitt is also a strong piece of timber placed vertically at the back of the windlass, and on which the pawls of the windlass are fitted. Winch-bitts are vertical pieces of wood to which the winch is fixed.

Blocks are large pieces of timber of about 4, 6, or 8 feet in length, and 16 or 18 inches in thickness, and on which the keel of the vessel is laid.

Blocks comprehend a system of pullies.

Bolts are pieces of iron or copper, in the form of pins, which fasten two pieces of timber together. Ring-bolts have an iron ring of about 3, 4, or 5 inches in diameter, passing through an eye or opening in one end of the bolt; when the bolt has merely an eye, and no ring, then it is called simply an eye-bolt. The ring-bolts are much used in ship-building. A few are fixed in the ship's deck or stanchions, for lashing the boats, or any other thing, down to the deck; the eye-bolts are also fixed in various parts of the hull, for hooking tackle, or fastening ropes to.

Bottom, that part of the ship which is below the load-water line or wales.

Bow, the fore part of the vessel above the water.

Boxing, is to scarph or join one piece of wood to another in a particular manner, as will hereafter be explained.

Braces are pieces of wood or iron, which bind or stiffen any part of the ship. Diagonal braces are those that cross any of the timbers in a slanting direction.

Brackets, short triangular pieces of wood used for supporting any thing.

Breadth, the measure of a ship from side to side in any particular place. It is usually distinguished into extreme breadth, main breadth, and top-timber breadth.

Break, any sudden rise or divergency from a straight or fair line.

Breast-hooks, large pieces of timber bolted across the inside of the ship's bow.

Breech of a timber, the lower part or joining of two legs or arms of the timber.

Bulwarks are planks to defend the vessel against the violence of the waves or the assaults of an enemy.

Bulkhead, a partition. Bulkhead is the name given to the boards or planks which separate one part or cabin from another.

Burthen is the computed number of tons of any merchandise that a vessel carries when fit for sea.

Bollard-timbers, or Knight-heads. (See the latter term.)

Bumkin, a piece of wood or iron projecting from each side of the ship's bow, and used for the purpose of spreading the foresail in ships and brigs.

Butt, is the joining endways of two timbers or planks.

Buttock, a part of the vessel near the stern, about the surface of the water.

Buttock-lines, lines used in the plan, to be afterwards explained.

Cable, a large rope to which the anchor is fastened.

Camber, a slight round upwards.

Cant-timber, that which is placed in a canting or sloping position.

Capstan, a cylinder revolving round a vertical spindle, having levers in it, whereby it is turned round. It is used to wind up any heavy body.

Carlings, pieces of oak, about 4 or 5 inches square, let into the beams of the vessel at each end, so that they are straight with the upper side of the beams, and lie in a fore-and-aft direction. Between the carlings, are pieces which lie parallel with the beams, called ledges.

Carvel-built, vessels or boats which have smooth bottoms, and whose planks are all flush, are said to be carvel-built, in opposition to those which have the edges of their planks overlapping each other, like the slates on a house, which are called clencher-built vessels.

Cat-head, a strong piece of oak projecting over the bow of the vessel at each side; these have sheaves in their outer end, through which a rope called the cat-fall is rove, and with which the sailors cat the anchor, or haul it up from the hawse.

Caulking, driving oakum between the seams of the planks, to prevent the entrance of water.

Cavity, the hollow formed by the sides and bottom of the ship.

Centre of cavity, the mean centre of the hollow formed by the sides and bottom of the ship.

Centre of gravity, that spot in the vessel upon which, were she placed or suspended, she would remain at rest in any position, *i. e.* she would be freely balanced in any position which she could possibly assume.

Centre of displacement, is the mean centre of that part of the ship which is immersed in the water. It is sometimes called the centre of immersion, and is the same as the centre of gravity of the mass of water which is displaced by the bottom of the ship.

Centre of percussion, is that spot in a revolving body (such as a ship when rolling or pitching), where the whole force or momentum of velocity is concentrated.

Centre of motion, a point through which the axis of a revolving body is supposed to pass.

Ceiling, the inside planks of a vessel.

Chain-bolts, those which fasten the chain-plates to the ship's side. Chain-plates are iron plates for securing the chain and dead-eyes, to which the shrouds are attached.

Channels, main, fore, and *mizen*, are pieces of timber or planks bolted edgeways to the ship's sides, in order to spread the rigging and carry it clear of the rail.

Channel-wales, thick planks bolted round the inside of the vessel opposite to the channels, in order to secure and strengthen the top sides of the vessel.

Chase, a long sloping mortise, into which a tenon is to be inserted.

Chinse, to caulk lightly.

Chine, a part of the water-way which is left above the deck.

Chocks, pieces of wood used for filling up any want or defect. At the joints of timbers cross-chocks are used; these scarph on to each timber, and connect the two together. It has long been customary to cross-chock the joints of different timbers. It has lately been proposed in the navy yards to make the timber to butt square upon each other, and insert a dowal half into each. This however, in my opinion, is not preferable to chocking the timbers.

Clamps, substantial planks put round the vessel on the inside of the timbers; the ends of the beams rest on them. The clamps are commonly bolted through every other timber of the side, and scarphed together with what is called hook-scarphs.

Cleats, pieces of wood of different shapes nailed or bolted on any particular part of the ship, either for belaying a rope to, or resting a shore against.

Clencher-built, when the planks overlap each other at the edges, and form projections on the bottom. Clencher-built vessels are much stronger, in proportion to their weight, than carvel-built ships.

Coamings, pieces of wood raised round the sides and ends of the hatches, to prevent the water from running off the deck into the hold.

Companion, a raised hatch or cover to the cabin-stair of a merchant ship.

Compassing or *Compass-timber*, pieces of timber which are incurvated or arched.

Converting the timber, is the act of bringing it into a fit shape for shipbuilding, by sawing and hewing it into the form required. It is nothing more than finding the proper pieces of timber to suit the different moulds with the least waste, and is a matter of very great importance to the shipbuilder. I have sometimes found foremen who were good converters of the material, and at the same time very indifferently qualified in other respects for carrying on the building of a vessel. I have also seen persons who were very good draughtsmen, and great wasters of the material.

Counter, a part of the stern of the ship between the wing-transom and the arch-board. Large vessels have two counters, a first and second; as the ship of 500 tons, *Plate* 24.

Counter-mould of a timber, is the reverse of the same.

Cramp, a machine for screwing two pieces of timber together.

Cross-chocks. See *Chocks*.

Cross-poles, temporary beams for keeping the frames at their proper breadth until the vessel is planked, and the proper beams put in.

Cut-water, the foremost part of the ship's head, or main stem.

Cutting-down-line, a curved-line formed on the plan or draft, for determining the height of the bed of the kelson.

Dagger-piece, a name generally given to slanting or diagonal pieces of timber, as the dagger-knees.

Daviot, a kind of cat-head for raising the anchor without injuring the ship as it ascends.

Davits, a kind of cat-head for fixing in the boat to assist in weighing the anchor.

Dead-eyes, a kind of block having only three holes, through which the *lanyards* are rove; the under ones are fixed to the chains, and the upper are attached to the shrouds of the rigging.

Dead-flat, the term for the midship section or midship bend; it is always distinguished by this mark ⊕; all the other frames or sections are distinguished by figures, or letters of the alphabet.

Dead-rising, the rising of the midship floor-timber from the horizontal.

Dead-wood, certain large pieces of timber fitted on the keel at the stem and stern-post, for the purpose of raising the floor-timbers and bolting to the heels of the cant-timbers.

Decks, the flats which are formed by covering the beams with plank; these run in a fore-and-aft direction, and constitute the decks of the ship. Large vessels have three or four decks, as the lower deck, the main deck, the upper deck and quarter deck, forecastle deck, poop decks, &c. A flush deck is one which is continued from stem to stern of the ship.

Depth in the Hold, one of the principal dimensions of a ship. For merchant-vessels the depth of the hold is taken from the under-side of the main-deck plank, at ⊕ frame, to the upper side of the ceiling-plank next the limbers.

Diagonal line, a line which is inclined to two other lines is the diagonal in reference to these two.

Diagonal ribband, a piece of wood made or bent to the shape of the vessel's bottom, either in the run or entrance; and its plane lies in a diagonal position from the horizon, and perpendicular thereto. The diagonal ribbands generally reach from the foremost square frame to the stem, or run completely round from the stem to the stern-post.

Diagonal shore, any shore or support that is not perpendicular from the ground, but is inclined.

Dovetail, a particular kind of mortise.

Douells, *Coggs*, or *Coaks*, cylindrical pieces of hard wood, about three inches in diameter, and the same in length; they are let half into two pieces of wood which are to be joined together. The bolts pass down through the axis of the douells.

Draught of water, the depth of water which a ship displaces, either loaded or unloaded. The former is called the load-water draught, the latter the light-water draught.

Drift-bolt, a bolt kept for driving or pushing out bolts. Drifts are breaks in the rails or upper-works.

Druxy-timber, timber in a state of decay, with white spongy veins through it.

Elevation, a perpendicular and longitudinal view of a ship. This is also called the Sheer Draught.

Entrance, a name frequently given to the foremost part of a vessel under the surface of the water.

Face of a timber, the moulding side, *i. e.* the side on which the mould is applied in shaping the edges of the timber.

Fair, not suddenly crooked. A fair curve is one having no quirked or flat parts in it.

False keel, *False stem*, *False stern-post*, or the like, is an additional keel, stem, or stern-post, fixed on the main keel, main stem, or main stern-post, to increase their strength, and make a ship hold a better wind.

Fashion-timbers, two timbers used in the runs of a vessel, which are fixed to the transoms and deadwoods.

Fay, is to fit close, or join two pieces of wood together.

Filling-in-timbers, are those between the frames.

A Filling is a piece of wood fitted on a timber, to make up a want or defect. The timbers should not have fillings if it can be avoided, particularly on their outside.

Flat, a straight part in a curve.

Flat-bottomed, signifies that the bottom of a vessel does not rise, and is little inclined from the horizon.

Flight, a sudden rise up, as the flight of the transoms.

Floor-plane, a part of the plan of a vessel.

Floor, the bottom of a vessel near midships. In the midship body, the flattest part of the floor is at the flat frame marked ⊕.

Floor-ribband, a diagonal ribband which is run round a vessel, a little below the floor-heads.

Floor-guide, is also a ribband which runs round a vessel, between the floor-ribband and the keel.

Floor-timbers, large and strong pieces of timber which extend across the keel; upon these floors the frames are erected.

Flush, is when two pieces of wood are checked into each other, and their surfaces become even. This term signifies a continuation of even surface.

Fly-up, a sudden rise upwards.

Fore and Aft, are opposite terms. In speaking of any plank, or thing, which is lying towards the bow and stern end of a ship, and not in a cross direction to her length, it is said to be lying fore and aft.

Fore-body, every part of the hull before ⊕, *i. e.* the dead-flat frame; and *After-body* is the hull abaft the same.

Forecastle, a short deck at the bow of the ship.

Fore-foot, the fore-end of the keel.

Fore-peek, a division of the hold, close to the bow, and is opposite to *after-peek*, which is a part of the hold at the stern post.

Frame of Timbers, in shipbuilding, signifies a number of pieces of timber bolted together, in order to form the bottom and sides of a vessel. It consists of the floor-timber—two first futtocks—two second futtocks—two third futtocks—two fourth futtocks, and one or two long and short top-timbers on a side. The frames are placed at right angles to the keel; some of our naval architects have proposed to put them at right angles to the load-water line, which is not parallel to the keel, when the vessel draws more water at the stern than at the bow.

Gallery, a balcony or scaffold, erected for the purpose of standing or walking on; or a kind of additional compartment, formed on the outside of the stern and quarters of large ships; it is called the quarter and stern galleries.

Gammoning-hole, a hole or mortise, cut through the head or cut-water, for the purpose of lashing the bowsprit down to the stem-head.

Garboard-strake, a course of the outside bottom plank next the keel of the ship.

Gudgins, a name applied to the hinges of the rudder.

Grain-cut, is when a timber is formed from a straight piece of wood, so that the direction of the fibre does not follow the curve of the timber.

Gripe, the under part of the stem and cut-water.

Ground-wayes, large pieces of timber sunk into the ground, and on which the blocks are laid.

Gunwale, a plank or wail which runs round the vessel's upper works, a little above the deck. In merchant ships it is called the covering-board, as it lies on the ends of the top-timbers, and the stanchions which support the rail pass through it. The gunwale is also called the Plank Sheer.

Half-breadth, is the distance measured from the centre line of the ship, to any of the sides. Half-breadth plane is a name for the floor-plane.

Handspike, a lever used for turning round the windlass and capstan.

Hanging-knees, are those which have one of their arms vertical.

Harpins, pieces of wood fitted to the curve of the bow; they are used to keep the bow to its proper curve, as laid down in the plan.

Hatches, openings in the deck through which any thing is lowered down into the hold. The fore-hatch is near the bow, the main-hatch is commonly in the middle of the ship, and the after-hatch is abaft the mainmast.

Hawse-pieces, large pieces of wood fixed on the bow, and through which a circular hole is cut, called the hawse-hole, for passing the cable through.

Head, an ornamental part at the bow of a ship.

Head-rails, pieces of wood belonging to the head.

Head-timbers, upright pieces of wood crossing the rails of the head, and binding them together.

Heel is the lower end or bottom part of any thing, as the heel of a timber, the heel of a mast, the heel of a ship, that is, the keel and stern-post at the lower end. It also signifies the canting or inclining of a vessel from the perpendicular position.

Height of breadth, the height to which a ship's side is carried before it begins to incline inwards.

Helm, a name for the rudder.

Hogging, the bending up of the keel of a ship by the vertical pressure of the water on the flat part of her bottom, or the falling down from the first position of the stem or bow, and stern, from not being sufficiently supported by the upward pressure of the water on these parts in proportion to their great weight.

Hooding-ends, the ends of the planks which butt against the stem and stern-posts.

Hold, that part of a ship in which the cargo is placed.

Hull, the sides, bottom, and deck of a vessel.

In-and-out, a term sometimes employed when speaking of the scantling or dimensions of the timbers, from the inside to the outside of a vessel.

In-board, the inside fastenings and bindings.

Intersection, that part where one line cuts another.

Jugle or *Juggle*, butting the narrow end of a plank on the bow or quarters into another plank without carrying it round to the rabbet; this plank is sometimes called a Steeler or Stawing-strake.

Keel, the principal piece of timber of a ship. It extends from the stem to the stern-post, and in a small vessel it may consist of one piece throughout. For those of a larger size, the keel is formed of two or three pieces, which are scarphed together, and laid on the blocks. The other timbers which compose the vessel are erected on it.

Keelson, or *Kelson*, an internal keel, placed immediately above the floor-timbers, and bolted down through every other floor and the keel.

Kevels, a kind of timber-head for belaying to.

Key, a kind of slip or wedge made of dry oak, and used for wedging any piece of wood tight into a mortise, which is larger than the tenon.

Knees, pieces of timber in the form of a right angle; they are sometimes made of iron, and are used for binding the beams to the ship's sides, the one leg or arm of the knee being bolted to the side-timbers, and the other to the beam.

Knight-heads are two timbers bolted to the stem, and between which the bowsprit is fixed; also called Bollard-timbers.

Knuckle, or *Nipple*, a sudden angle made on a timber by a reverse of shape, such as the knuckles of the counter and stern-timbers.

Laboursome, a vessel is said to be so when she pitches or rolls very much.

Launching, the sliding of one piece of timber upon another.

Launching, the act of sliding a ship into the water.

Lapsided signifies that both sides of a ship are not exactly alike.

Larboard-side is the left side of a ship when a person stands with his face to the bow.

Laying-off or *Laying-down*, transferring the plans of the ship from the paper, to the full size on the floor of the moulding-loft.

Lean, or *Clean, and Full*; the first two signify that the ship is sharp—the second, that she is not so.

Let-in, to let in one piece of wood into another.

Level-lines are lines parallel to the horizon.

Limbers, an opening between the bottom of the floor-timbers and the garboard-strake, making a passage to the pumps for the water which gathers in the ship.

Lips of scarphs. When the sharp points of the scarph is cut off, it forms a lip, by which there is less chance of the points of the scarphs splitting, as they have a thicker point they will hold firm against the opposite chack in the other piece of timber.

Luff of the bow, the part near the cat-head.

Magazine, an apartment for holding gunpowder.

Main, the principal part or piece, as main-mast, main-stay, &c.

Main Breadth, the extreme breadth of the ship.

Meta-centre, is that point where a vertical line drawn from the centre of immersion cuts a line passing through the centre of a ship whenever she is heeled over.

Middle-line, a line which divides a ship into two equal parts from stem to stern-post.

Midship Bend, a name given to the midship-frame.

Mortise, a recess or notch made in one piece of timber, to receive a corresponding projection on another; the projecting part is called the tenon.

Moulds are thin pieces of fir formed to the shape of the timbers. Moulds for drawing the plans of vessels are thin pieces of pear-tree, of different forms, such as parts of circles, ellipses, &c.

Nails, iron pins for fastening one piece of wood to another; they are made of different

forms and strengths, according to the purposes for which they are intended. A spike-nail is the largest kind, varying from 4 to 8 or 9 inches in length; ribband-nails are large round nails made with round heads—they are chiefly used for nailing the ribbands to the timbers, or nailing a cleat which requires to be taken off again; clamp-nails are short and thick, and are used for fastening iron plates or the like. The nails which are used for nailing down the deck-plank to the beams are made of copper and tin.

Night-heads. See *Knight-heads.*

Oakum, a material made of old ropes, and used for caulking a vessel.

Overhang is when any part of a vessel rakes out, such as the stern.

Overlaunch, to run the end of one plank over that of another.

Out of Winding, is when one part is not twisted from another, or when the surface of a timber is a direct plane.

Pawls are iron or wooden rackets; they are fixed to the pawl-bitt, and near the capstan, to prevent the windlass or capstan from recoiling or turning round in a backward direction.

Paint-strake, or *Sheer-plank*, the uppermost strake of plank on the vessel, terminating the sheer or vertical curve of the top-sides.

Partners, thick plank, or other pieces of timber, firmly fixed between the beams, and which form an opening for the mast, or for steadying any upright pieces which pass down through the deck.

Pink-sterned, is when the stern is rounded-in below, and finished with a very narrow square part above.

Pintles, that part of the hinges of the rudder, having a strong pin at the fore-end of the braces, which passes down through a circular hole in the after-end of the braces, which are fixed on the stern-post. The pintles are attached to the rudder.

Pitch, tar boiled to a harder and more tenacious consistency. When cold, it is quite hard.

Pitching, a dangerous rising and falling of a ship's bow and stern alternately, owing to the swell of the sea.

Plan, a drawing formed by lines bearing positions and proportions to each other, in the same ratio as the different parts of the real or intended building do to each other, but drawn to a proper scale.

Plane, a surface perfectly straight in every direction.

Plank. Wood much less in thickness than in breadth is called plank; the act of covering the timbers of a ship with this, is called planking.

Plank, Sheer, or *Gunwale*, a name for the covering-boards.

Poop, the uppermost deck at the stern.

Ports, openings in a ship's sides or bulwarks.

Preventer-bolt, a bolt driven through the lower edge of the preventer-plate, to secure it, and thereby lessen the strain on the chain-bolt.

Preventer-plates, strong iron plates attached to the chains, and bolted to a ship's side.

Prow, the French name for bow of the ship.

Quarter, the top-sides of a vessel near the stern end.

Quarter-deck, a part of the deck from the stern to the main-mast.

Quarter-galleries, a kind of additional cabin projecting without the quarters of a vessel.

Quarter-pieces, stout pieces of oak bolted on the outside of the plank-ends at the quarter-timbers.

Quarter-timbers, timbers in the quarters of a vessel.

Quicken, to give a curve or line a quick turn.

Quick-work, strakes of plank wrought between the spirkittings and the clamps.

Rabbet, or *Rebate*, a kind of V groove cut along the upper edge of the keel, for the purpose of receiving the edge or end of any planks that are to fit against it. There is a rabbet cut on each side of the after-edge of the main stem, and fore-edge of the main stern-post, into which the ends of the planks butt.

Raft-port, a large port or hole formed at the breast-hooks in the bow, or transoms at the stern, for taking in or out cargoes of timber.

Rag-pointed bolt, or *Barb-bolt*, a sort of bolt having its point like that of an arrow. They hold very fast, and cannot be easily drawn; they are used for bolting, where a common bolt could not be clinched.

Rails, any long narrow pieces of timber put round the deck at a convenient height, to prevent the crew from being washed overboard. The main-rail reaches from the stem to the stern; the taffrail is a continuation of the main-rail across the stern.

Rake, the overhanging of the stem or stern beyond the perpendicular line.

Ramed—a new vessel is said to be ramed when all the frames are set upon the keel, and the stem and stern-post are also put up.

Reconcile, to join one line or curve fair with another, so that no flat or quirked part shall be observable at their junction.

Reeming, opening the seams of the plank with iron wedges, that the oakum may be properly admitted.

Rents, or *Shakes*, are openings which take place in timber when much exposed to the heat of the sun, sometimes to such an extent as to render it unfit for many purposes.

Ribband-line is one formed by the extreme of a diagonal and longitudinal section of a ship's bottom.

Riders, strong pieces of timber bolted on the inside of a vessel to increase her strength.

Rising floors. The floor-timbers near the bow and stern are called rising floors, as they are more curving than the midship floors.

Rising line, a line used in the sheer plan.

Rolling, the motion of a ship from side to side, occasioned by the action of the wind and waves. This motion is affected in a great measure by the form of the ship and the position in which the cargo is placed. In the theory of the rolling motion, a ship is considered to vibrate round an axis which passes through her centre of gravity. From the action of the water on the cavity of the ship, if the centre of gravity be high, she will be easily overset by the action of the wind or waves; on the contrary, if it be low near the keel, the stability will be much increased, although the rolling motion will be increased. (*See* observations on the rolling motion.)

Rudder, a machine used for steering a vessel.

Rudder irons, a name for the braces and pintles or hinges of the rudder.

Run, a part of a ship's bottom, abaft the midship body, and under the water.

Saddle, a piece of wood fitted on the masts of smacks to bear up the inner end of the boom.

Scale out, is when a vessel has an inclination outwards at the bow.

Scale, a miniature representation of the measurements of feet, with their divisions into inches, &c.

Scantling, the dimensions of a piece of timber.

Scarphing, joining two pieces of timber together, by overlapping the end of one piece over the other, but having both points thinned off, so that when joined they appear as an even surface.

Scroll, a spiral ornament.

Scuppers, lead or copper pipes, passing through the ship's sides at the decks above water, to allow the water to run off the deck.

Scuttles, square openings cut through the deck.

Seams, the joints of the planks.

Seat, the bottom part of a timber; the seat of the floors is that part which rests on the keel.

Section, the representation of any solid after it is cut by a plane. The whole art of ship-draughting consists in forming proper sections of a vessel, and reconciling them with each other; the different sections receive their names from the figures which they cut or produce, and from the position of their cutting planes. Thus, a section cutting a vessel perpendicularly, and in the direction of her keel, is called a longitndinal section. If it cut the vessel perpendicularly, but at right angles to the length, it is called a transverse section; because the former may be considered as the conjugate section, in reference to the conjugate and transverse diameters of an ellipse. A horizontal section is one whose cutting plane is parallel to the horizon; and a diagonal section is one formed by a plane which is more or less inclined from any of these former positions.

Shank-painter, the name of a chain attached to the bow of a vessel, near the cat-head, to retain the shank and flues of the anchor.

Sheathing, thin boards or sheets of copper nailed on the bottom of a vessel, to protect it from worms.

Sheer, the curve or bend downwards in the middle of the top-sides, or upper-works of the vessel.

Sheer-plank, *Sheer-strake*, or *Paint-strake*, broad strakes of plank put round the vessel at the top of the timbers. They are commonly thicker than the other planks of the top-sides. On the lower edge of the paint-strake, a moulding is formed, corresponding with that on the edge of the gunwale or plank-sheer.

Sheers, two spars or masts lashed together at one end, and set up like the two legs of a triangle; to their upper point a block and tackle are attached. They are used for hoisting up the stem, stern-post, the frames, &c.

Shiftings of the planks, a term used for expressing the arrangements of the planks, so that they may overlap one another with their ends, forming a shifting of their butts, and bind the ship. When English plank is used, the shiftings or overlaunchings of the plank is five feet, or five feet and a half; but when foreign timber is used, they are generally made seven feet, and there are always three strakes of plank between butting on the same timber.

Shores, pieces of timber employed as props or temporary supports in shipbuilding.

Siding-dimension, is the breadth of the timbers; *moulding-dimension* is their thickness.

Sir-marks, a mark made on the moulds of the timbers, to distinguish the spot where the bevel is to be applied in bevelling the timbers.

Sliding keels, large pieces of wood, made to lower down through the main keel of the vessel. *Vide* description of *Plate* 15.

Sliding planks, pieces of wood which are laid on the bilge-ways, and slide the vessel into the water when launching.

Slip, the inclined or sloping surface of the ground on which the ship is built.

Slip, Mr. Morton's patent, a frame or cradle, which is drawn up or let down at pleasure into the water, having a great number of small wheels running upon a railway or inclined plane. It is used for hauling ships out of the water to be repaired. When the vessel is to be hauled up, the cradle is let down, and from its having a good deal of iron about it, it has no tendency to float off the railway;—the vessel is then brought above the cradle, and as soon as ever she bears upon it, the cradle is drawn up, bringing with it the ship, which, by the strength of only a few men, is thus completely hauled up.

The principal object of this invention is, to provide a cheap substitute for dry docks, where it has not been thought expedient or practicable to construct them; and, both in point of economy and dispatch, it has been found completely to answer the purpose for which it was originally intended.

The patent slip, after the extensive experience that has now been had of it, is admitted to possess the following advantages:—

1. A durable and substantial slip may be constructed, under favourable circumstances, at about one-tenth of the expense of a dry dock, and be laid down in situations where it is almost impossible, from the nature of the ground, or the want of a rise and fall of tide, to have a dock built.

2. The whole apparatus can be removed from one place to another, and be carried on shipboard.

3. Where a sufficient length of slip can be obtained, a number of vessels may be upon it at once; and, in point of fact, two or more are often upon the slips already constructed, and under repair, at the same time.

4. Among the other advantages peculiar to the slip, it may be observed, that, every part of the vessel being above ground, the air has a free circulation to her bottom and all around her; in executing the repairs, the men work with much more comfort, and of course more expeditiously; and, in winter especially, they have better and longer light than within the walls of a dry dock; while considerable time is saved in the carriage of the necessary materials. The vessel, in short, is in a similar situation to one upon a building slip.

5. No previous preparation of bilge-ways is necessary, as the vessel is blocked upon her keel, the same as if in a dock; and she is exposed to no strain whatever, the mechanical power being solely attached to the carriage which supports her, and upon which she is hauled up.

6. A ship may be hauled up, have her bottom inspected, and even get a trifling repair, and be launched the same tide; and the process of repairing one vessel is never interrupted by the hauling up of another,—an interuption which takes place in docks, from the necessity of letting in the water when another vessel is to be admitted.

7. A vessel is hauled up at the rate of 2½ to 5 feet per minute, by six men to every 100 tons; so that the expense both of taking up and launching one of from 300 to 500 tons, does not exceed *forty shillings*.

Snying, A plank is said to have snying when it is much curved or bent edgeways.

Spiles, small wooden pins driven into nail holes, to prevent a vessel leaking.

Spilings, the dimension of the twisting or curving of a plank, measured from the edge of

a batten or rule-staff. When the snying of a plank is to be measured from the bottom of the vessel, a straight-edged batten, of four or five inches in breadth and half-an-inch in thickness, is applied, quite flat against the timbers; it is placed in the direction of the intended plank, as near as possible without bending it edgeways, (this is termed pending the batten or staff.) You then measure from the edge of the batten to the seam of the plank put on last, against which the other is to fit, and mark the distances on the batten, taking a measure perhaps at every $1\frac{1}{2}$ or 2 feet apart. The rule or batten is then taken down from the timbers, and laid on the plank which is intended to be lined off. The same distances which are marked on the batten are then measured from the edge, and marked on the plank; and after they are all measured off, the plank is lined to the proper curve edgeways. This is called the Snying of the plank.

Spirkitting, is a strake or two of plank wrought round the inside of the top-timber, between the waterways and the under side of the port-sills. In merchant ships, there is only a short strake at the bow, and it is sometimes called quick-work.

Square. A piece of timber is said to be square when its sides form right angles to each other.

Square frames, those that have the planes of the sides of the timbers at right angles to the keel.

Square tuck, a name given to a part of the after-run, when it ends in a straight plane, which is nearly vertical, in place of the plank running up to the counter.

Stability, the property which enables a ship to stand upright in the water, and also to regain that position when the force which has caused her to deviate from it is removed.

Stantion or *Stanchion*, a support.

Standards, large iron knees fitted between the beams of the upper and 'twixt-decks, bolted to these beams and the ship's side. They are sometimes called iron staple-knees.

Staples, crooked pieces of metal used for various purposes.

Starboard-side, the right-hand side of a ship when standing aft with your face to her bow.

Steeling-strake or *plank*, one which does not run all the way to the stem or stern-post.

Steering-wheel, a wheel to which the tiller-rope is attached, used for steering the ship.

Stem, the principal timber which forms the bow of the vessel, into which the ends of the bow-plank are fixed.

Stemson, a large knee fixed on the inner side of the apron, and upper side of the upper keelson.

Steps of the Masts, a large piece of timber bolted down to the keelson, having a mortise in it, which receives the tenon on the lower end of the mast. Sometimes the step for the mizen-mast does not lie upon the keelson, but rests upon a large piece of timber fixed between two of the hold beams.

Stern, the after part of a ship above the counter, and in which windows are made to give light and air to the cabin.

Stern-post, a strong piece of timber, generally extending from the keel to the upper-deck. It fits to the after end of the keel with mortise and tenon, and is fastened by the deadwoods and heel-knee.

Stern-post, inner. The inner stern-post is fitted on the fore side of the main stern-post, and generally extends from the keel to the under side of the wing transom.

Stools, pieces of plank which are bolted edgeways to the quarters of small vessels, to form the mock quarter-galleries.

Stringers, strakes of planks wrought round the inside at the height of the under side of the

beams. They are bolted to the clamps and timbers, and are hook-scarphed. As they are put on edgeways, and serve as a shelf to rest the beams upon, they are sometimes called shelf-pieces.

Tabling, making projections and recesses alternately on two pieces of timber which are to be fastened together; the tablings prevent the pieces from drawing or slipping upon each other.

Taffrail, the continuation of the main-rail across the stern.

Tenon, a square projection on the end of a piece of timber or surface, corresponding in size and position to a hole or mortise in another piece, to which it is to be joined.

Thick-stuff, a name for a plank which exceeds four inches in thickness.

Throat, the middle or centre part of the hollow of a timber, knee, or breast-hook.

Tiller, a lever fitted into the head of the rudder for steering a ship.

Timbers, the ribs of a ship; the pieces of wood of which the frames are composed.

Timber and Room, *Room and Timber*, or *Birth and Space*, mean the distance from the side of one timber to the same side of the next; or the distance from moulding edge to moulding edge; the birth and space of the timbers is always 1½ or 2 inches greater than the breadth or siding dimension of the timbers, and can never be less.

Tonguing, the forming a kind of tenon on the end of a piece of timber which is to butt against another.

Tonnage, the cubical contents of a vessel, reduced to the number of tons which she will carry. Owing to the various constructions of vessels, and as they are all measured by the same rule, and not actually gaged, some carry more than their calculated tonnage, while others carry less.

Top and *Butt*, in planking, mean working the plank in the anchor-stock fashion, laying their broad and narrow ends alternately fore and aft. This is practised, in order to save materials, when planking with English oak.

Top-sides, all the ship's sides above the bends.

Top-timbers, timbers forming the top-sides.

Touch, the broadest part of a plank worked top and butt, which place is about five or six feet from the butt end.

Trail-boards, pieces of fir fitted between the cheek-knees of the head; they are carved with a device corresponding to the figure-head.

Transoms, large pieces of timber which lie horizontally across the stern-post, and form the buttock; they are bound together at the end by a timber called the fashion-timber.

Transom-knees, knees bolted to a ship's quarters and the transoms.

Trimming a piece of timber, working it to the proper shape and bevelling.

Treenails, cylindrical oak pins driven through the plank and timbers to fasten them together.

Trim of a vessel, the proper adjusting of the sails or cargo.

Truss, a carved bracket employed to support the carved work over the stern-windows.

Tuck, the place where the butts of the bottom plank in the after-run terminate; generally a little above the wing transom; and at this place a large moulding is wrought across the counter, which is called the tuck-rail or tuck-moulding.

Tumble-home, the inclination inwards of the top-timbers towards the middle of a vessel.

Under-bevel, a bevel that is within a square.

Unship, to remove any thing out of its proper situation on board a vessel.

Upper-deck, the uppermost deck that extends from stem to stern.

Upper-works, a name for that part of the hull of a vessel above water.

Waist, a name given to that part of the upper-works above the main-deck and between the main and fore-channels.

Wales, the principal strakes of thick plank, wrought round the outside of a vessel, about the load-water mark. They are sometimes called the bends.

Wash-board, a strake of plank in the bulwarks, put on with small bolts and fore-locks; it can be taken off at pleasure, in order to get the stantions properly caulked.

Water-lines, names applied to certain lines used in drawing plans of vessels.

Windlass, a strong piece of wood turning round on an iron spindle, which is fixed into its ends; it lies in a horizontal position across the ship, and is turned round by levers, called hand-spikes.

Whelps, pieces of wood or iron bolted on the windlass, to save the main piece from being chafed by the cable.

Whole-moulding, an old method of moulding vessels, now almost out of use, except for boats.

Winch, a small windlass.

Wing-transom, the uppermost of the main transoms.

Wood-lock, a piece of wood fitted into the fore part of the rudder, to prevent it from being unshipped.

Wrain or *Wrung-bolts*, ring-bolts used in planking.

Wrung-staff, a piece of wood used also in planking.

Yards, long cylindrical pieces of timber, suspended across the masts, to extend the sails to the wind.

In addition to the above explanations, see Plate X. which exhibits all the principal pieces of timber, and the method of binding and fastening them together in their respective places.

Observations on the Sailing, and on the Rolling and Pitching Motions of Ships.

It would be impossible to give an account of the numerous theories that have been proposed to determine the best form and construction for fast-sailing vessels. Since the first invention of ships capable of performing long and difficult voyages, the different theorists have attempted to construct vessels which should outstrip all others in sailing. Of course, each individual acted according to his own principles, or endeavoured to improve on the construction of those vessels which had proved to be superior to others with whom they had been compared; but it has often been found that the performance of these vessels fell short of what was expected. At the same time, there is no doubt that such attempts tend, in no inconsiderable degree, to improve the art of shipbuilding.

It is well known that considerable improvements have been made on the sailing of some vessels, in consequence of the strict attention which has been paid to their proper

sailing trim, the situation of the masts, &c. It is no less certain that the most experienced commanders have been unable, although the utmost attention has been paid to these particulars, to make the slightest improvement on the sailing of their vessels. I do not pretend to account satisfactorily for this incongruity; but it is generally allowed, that although a great deal depends upon the skill of the master or captain, as regards stowing the cargo, and carrying proper sail on the vessel, yet the principal object consists in giving the ship a proper form, particularly in the bottom.

It has been the object of all maritime nations to have their navies composed of fast-sailing vessels; and it has been found that those who contributed principally to this object were the persons who were most intimately acquainted with the building and sailing of these ships. Philosophers have indeed directed their attention to this subject, but in general have not condescended to profit by the assistance which practical experience might have afforded them; and consequently their theories have been of little advantage to the shipbuilder.

It is not my intention to discuss whether the French, Americans, or the British, are the most expert in shipbuilding, or which of their navies contains the greatest number of fast-sailing vessels. As much has been said on every side, and much difference of opinion still exists on this point, I shall not rake up the ashes of a controversy of little importance. The heavy duties and restrictions laid on the commercial shipping of this country have been a great bar to their improvement; yet notwithstanding this disadvantage, there is no class of merchant vessels in the world which possesses what are usually considered the primary principles of perfection, *i. e. strength, capacity, stability,* and *velocity,* in such due proportion as British merchant vessels. There is none that will sail with them, taking *weight for canvas.* At the same time, it is not to be expected that a large and deeply-laden vessel, with a small proportion of canvas, is to sail equally fast with those that are built more particularly for velocity than stowage. Vessels built for carrying great cargoes in proportion to their size, must necessarily be full in their bottoms, and therefore be more difficult to propel through the water than those on a sharp construction.

Few persons are aware of the sacrifices of capacity which are made to procure fast-sailing vessels. The resistance which a vessel meets with in passing through the water increases as the squares of her velocity. The power necessary, however, to produce different velocities, is said to be as the cubes of these velocities; *i. e.* if a power of 3 impel a vessel at the rate of 3 miles per hour, it will require a power of 27 to double her rate of velocity. It is found that a quadruple power will only at most produce a double motion in any machine whatever. Now, if one vessel sail at the rate of 7 miles per hour, with a power of 20, the force necessary to make her sail at the rate of 11 miles will be as the cubes of these velocities; as $7^3 : 11^3 :: 20 : 77.6$, nearly in the ratio of 4 to 1. This may serve to illustrate the comparative advantages of two vessels, and shew, that where very great dispatch is not required, we should be content with a moderate velocity, and not expect merchant vessels to sail equally fast with those built for fast sailing. There must, however, be a limit to increasing the velocity of a vessel, by reducing her capacity, and making her so very sharp; for there is a certain degree of

sharpness, beyond which any farther extension will destroy every good property which she can possess. There is a great risk in sailing these extremely sharp vessels, as they run a chance of being pooped, should there be a heavy sea. This is sufficient to make us prefer a safe and comfortable vessel; and she is not the best ship that sails fastest, unless she possess other good properties.

Theorists and mathematicians have ventured to decide on the form best adapted for fast-sailing vessels;—elaborate calculations have been made, by which the curve or solid of the least resistance is said to have been discovered; but it unfortunately happened, that when vessels built according to such calculations were sent to sea, they were found not only to want the advantages attributed to them, but to be inferior to those constructed by practical individuals, in respect of being good sea-boats. Though the application of many of these theories has tended in some degree to bring our subject into contempt, still the remedy has not been distant. They have convinced numerous individuals, that however scientifically they may have been got up, they are undeserving of any confidence, when inconsistent with what practical experience has proved to be absolutely necessary in the construction of vessels, with reference to the purposes for which they are intended. There can be no hesitation in affirming that improvements must be effected through a more certain channel than that of abstruse investigation by persons having little practical experience. When a strict attention has not been paid to the form of the vessel's bottom—to the dimensions and proportions of those which are known to possess superior properties, no improvement can be expected. It is one of the vexations attending improvements in this art, that one can only be procured too often at the expense of another: of course, it becomes a matter of calculation which is the more advantageous.

Mr. John Major, foreman in one of his Majesty's dock-yards, has published the only rational method (in the Annals of Philosophy for the year 1824) by which we can expect to obtain a correct theory for the construction of ships of war. The great theorists may condemn this plan, but practical men have come to a very different opinion. Mr. Major recommends that an analysis of about 200 vessels should be obtained, from which a criterion might be derived that would be the only certain guide in our attempts to improve the construction of ships. In the course of my profession, such is the method which has been employed. During the last 25 or 30 years, I have drawn the plans of nearly 100 vessels of almost all descriptions, which have been correctly built from these plans; and having inquired particularly into their character and performance at sea, it is only by comparing their draughts, and considering the properties which each possesses, that I am sensible of a defect, and how it may be avoided in future. Every shipbuilder is aware of the advantage of having a set of correct draughts or plans of vessels that have been found to answer well.

On the Stability of Ships, and on their Rolling and Pitching Motions.

It has often been remarked, that fishes move through the water with amazing velocity, and that those which swim fastest have a form best calculated for opening a passage through the fluid in the most uniform manner, and consequently suffer little resist-

ance. It is generally supposed that the ancients, who must have been aware of this, formed the bottom of their ships or gallies like the shape of some finely-tapered fish; for it is not to be supposed that they were sufficiently acquainted with the laws of the resistance of fluids, as to deduce from mathematical investigation the most proper form of bodies of given dimensions to move in a fluid with the least resistance. Such knowledge seems to be a desideratum even at present. Although there are scarcely two vessels whose bottoms are of the same form, and alike in every respect, yet they all have bottoms more or less calculated for dividing and closing the fluid, although some are but very indifferently formed for that purpose.

Before attempting to form an idea of the shape of the bottom and form of a vessel that may possess as many good properties as possible, we shall first examine the laws of those motions, &c. to which the vessel is subject on account of the action of the wind and waves, after which some idea may be formed of what is required.

It is perhaps necessary to mention, that the steadier a vessel goes through the water the better. A vessel that rolls or pitches heavily, will not be a fast sailer, nor will a crank ship (*i. e.* a vessel which is easily laid over by the action of the wind on the sails); for in this case she is not able to bear a sufficient quantity of canvas, and by being heeled over, she presents an unfair part of her bottom to the action of the fluid. Although stability is an essential property, yet there is an evil which attends vessels that are too stiff, viz. that of carrying away their masts, and being laboursome in the sea. All experienced shipbuilders are aware of this, and endeavour to give their vessels such a form as will confer only the necessary degree of stability, which, it is hardly necessary to observe, is one of the essential properties which every vessel should possess.

On the Laws of Stability.—It is a general law which affects all floating bodies freely immersed in a fluid, that they will displace a quantity of it equal to their weight, and will always endeavour to attain a state of rest with their heaviest sides or ends downwards. This arises from the effect of gravitation, which acts upon all bodies in proportion to the density of their parts, *i. e.* equally upon any two bodies having the same number of equal particles of matter, without regard to their form. It is also a law, that all bodies of a uniform shape descend or move with their centres of gravity foremost. If you throw a uniform body up into the air, whose centre of gravity is near one end, it will turn round, and descend with the heavy end downwards. Suppose A B (*Plate* V. *Fig.* 105) to be a piece of light wood, to the end of which is joined a piece of heavy wood, so that the centre of gravity of the whole body A C is in the point *e*, and not in the middle of its length, D. Now, suppose the body to be allowed to fall from the horizontal position, its whole weight being concentrated in its centre of gravity *e*, that point will descend in a straight line; however, the body will not descend horizontally, but turn with its end C downwards, and in turning, the point *e* will be its centre of rotation; for the end *e* C, although it is of the same weight as *e* A, does not suffer the same resistance from the medium through which it descends; the end *e* C will therefore fall fastest from the horizontal position, and if the body have a sufficient height to fall through, it will come into a vertical position, and at length strike the ground with its end C. This is entirely

owing to the resistance which the different parts of the body on each side of the centre of gravity meet with in passing through the air. If the body is not of a uniform shape throughout, that end will fall first which suffers least resistance from passing through the air or water. Suppose a body of a similar shape to E G F (*Fig.* 106), of which G is the middle, and *e* the centre of gravity, to be let fall from the horizontal position; now, although the centre of gravity is nearer the end F than E, yet if the resistance to the end *e* F be greater than that to the end *e* E, the end F will not descend swiftest, but the end E will become the lower end while the body is descending, and of course strike the ground first.

The surface of the water forms a large part of that circular plane which limits the earth's surface, and as the action of gravitation tends in straight directions from every part of that surface to the centre of the earth, every body that is freely suspended from this surface will hang with its line of suspension at right angles to it; and if the body be supported in a reverse position on that surface, it will stand with its line of support upright. If a body be suspended at equal distances from two or more points in that surface, it will be perpendicular to a point in the centre of their extremes. It is evident, therefore, from these premises, that the surface of a quiescent fluid becomes a base perfectly level and smooth, on which all equally-balanced floating bodies will be sustained in a vertical position, in equilibrio with the upward pressure of the fluid; and thus we are led to perceive, from the laws of rest and motion, how ships are made to stand upright with all their masts, sails, &c., and prevented from oversetting when pressed to a moderate extent by the action of the wind on the sails. For this purpose, however, something more must be attended to, than merely that the weight of the vessel is equal to the weight of the volume of water which she displaces, for this condition would only ensure us that the upward pressure of the fluid and the downward pressure of the vessel were equal, but not that they had destroyed the effect of each other, it being only equal and directly opposite forces which destroy each other. In order to ensure a state of rest in an upright position, the vertical line which passes down through the centre of gravity of the ship, must coincide with the vertical line which passes up through the centre of the displacement, *i. e.* the centre of gravity of the fluid which is displaced by the body; or, which is the same thing, the straight line which joins the centre of gravity of the body and the centre of immersion must be perpendicular to the surface of the water. We may mention that the centre of displacement, immersion, or centre of support, is the same point. If all external force be withheld from the floating body, it will come to a state of rest with its centre of gravity and the centre of immersion vertical to each other, as shewn in the 8th proposition of Hydrostatics. (*See Introduction, page* 84.)

The length and breadth of a ship form the extremes of a base on which we may suppose her to rest, and she will only swim upright with the centre of gravity in a line passing up through the middle of her breadth, when both sides are exactly alike in form and weight. But all ships are, or should be built equally on each side of the longitudinal axis, and have their centres of gravity situated in the plane of that axis about the surface of the water; therefore they stand upright, and are at rest if the fluid be

so, and no external force acts on, or motion takes place within them. But the ship will have a certain power, by which she will resist every attempt to change that natural state of rest, in proportion to her particular form, the situation of her centres of gravity, cavity, and immersion; and by these will her stability, rolling and pitching motions, be regulated, whatever may be the force which is employed to produce these motions. The fundamental principles of stability have been explained in the 8th and 9th propositions of Hydrostatics (*see Introduction, pp.* 84 & 85), and we shall here consider the effect of different forms of the floating body in relation to ships. I shall endeavour to discuss the subject in a plain and simple style. In the first place, I shall make an observation on solid bodies resting on the ground. By the laws of motion and rest, a body will be in motion if its centre of gravity be not sustained and at rest; and it cannot be at rest until its centre of gravity is sustained. Suppose a block of wood or stone to be resting on the ground, as A, *Plate* V. *Fig.* 107, of which g is the centre of gravity sustained. But suppose the block to be canted into the position B, in which the centre of gravity is not sustained, being at one side of the line of support, then the body will not remain in that position, but will fall back into that of A; and this will always be the case while the centre of gravity is within the vertical line of the base. But suppose the body canted into the position C, where the centre of gravity g' is without the base, not being in the line of support, then it will fall over. This illustrates the stability and oversetting of ships. They may be heeled or canted over by the pressure of the wind on the sails, to a certain extent, and regain their upright position when the wind abates; but should they be canted so far over that their centre of gravity comes to the same side of the line of support that the vessel is heeled too, she will overset completely.—In the next place, let us consider the force necessary to cant a body on the ground, and then see the difference between the heeling or canting of a ship to one side in the water. In canting a body resting on the ground, it is certain (from the principles of the lever) that only one-half of its weight will require to be lifted, if the centre of gravity be in its middle; for in the act of canting, the ground will support the other half. As you continue to raise up one side of the body, you increase the weight on the ground at the other side, by moving the centre of gravity nearer the vertical line which passes up through the corner on which the body is canted, and thereby easing the weight of the lifting side; so that whenever the centre of gravity becomes vertical to the point of support, the whole weight of the body is on the same, and the smallest force will push it over, or cause it to fall back again to its first position. From this it appears, that in canting a solid body over on the ground, the first is the greatest lift, and equal to one-half of the weight of the body. The action of canting or heeling a vessel immersed in water to one side is entirely different. All floating bodies displace a quantity of water equal to their own weight, and the quantity so displaced will be equal in bulk to the part of the solid which is immersed; so that ships whose sides are equal in form and weight, displace equal quantities of water, and a ship floating thus is said to be upright. We may consider a vessel floating in a fluid to have her centre of gravity above or below the surface of the water—that she is resting as it were upon one single point, supported by the upward pressure of the water. The friction of water

is so small, compared with that of other tangible substances, that the extremities of the two sides or ends of the ship become like the ends of a balance beam, which the slightest force either raises or depresses. A very small force will be sufficient to produce motion in a floating body, and to cant or heel a ship to a certain extent; but no force less that what is able to cant a solid rectangular body completely over, will be sufficient to produce the least motion from its state of rest. Hence the power, from the action, to cant or heel a vessel to one side, is completely different, and cannot be estimated according to the rule given for canting solids on the ground; for we find, that a very small power applied to one side of a vessel will cant her, and produce motion to a certain extent. All changes from the first state of rest will be in proportion to the power employed to produce them; and every power less than that required to overset the vessel will heel her to a certain extent, but no farther, because the resisting power will increase with the change of position, until it acquires its greatest force, after which, as the vessel is farther heeled over, it will continually diminish, until it at last vanish, and the vessel be completely overturned.

Let the straight line A B (*Plate* V. *Fig.* 108) represent the surface of the water; let *Fig.* C represent the midship section of a vessel in an upright position; let *g* be the centre of gravity of the whole vessel, and *i* that of the part under water, *i. e.* the centre of displacement; then, in this position, these two centres are vertical to each other. Now, suppose the vessel heeled over by some force on the masts into the position D, it is evident that she has raised a portion of one of her sides, as *p q*, out of the water, so that the same side does not displace the same quantity of water that it did before by the portion *p* L *q*; but the opposite side has displaced a greater portion than it did before, and which is exactly equal to that which the other side is minus, that is, the quantity *r* L B.

Now, without considering the effect of the force which heeled the vessel over, in altering the position of the centre of gravity *g*, we find that the position of the centre of displacement is altered, from being in the axis of the vessel at the point *i*, to some distance from the same, as to *i'*, that being now the centre of gravity of the immersed part B *r y p'*. Now *i'* is the point of support; and the vertical line passing up through the same cuts the axis of the vessel in the point *m*, which is called the meta-centre.

Again, the vessel will continue at rest in the position D, if the force which first inclined her to the same is not removed. Next let us see what effect this force upon the ship will have in altering the position of her centre of gravity. First, it will have the effect of changing that point, and bringing it in the line of support *i m*; and it must be in that line, otherwise the vessel could not remain at rest in the position D; for it is a condition of floating bodies in a state of rest, that the centre of gravity and support are in the same vertical line.

Having established that the new centre of gravity, when the vessel is in the state of equilibrium represented by *Fig.* D, is in the vertical line which passes through the point of support *i*, we shall not at present consider whether it is raised higher in the ship than before, because many circumstances render this a matter not to be easily determined, such as the nature and place at which the power to heel the vessel is em-

ployed; but we shall see what the extent of that force is which holds the vessel in the inclined position, for it must be equal to the resistance which she presents to the same; and this we can easily find: Let W be the weight of the vessel in tons, concentrated in the centre of gravity g'; conceive her to be hinged on the point i, or to turn on that point as a fulcrum; then the horizontal distance of the centre of gravity from that point is the lever by which she acts in resisting the inclining force, *i.e.* the distance g S, which we may call a; then $W \times a$ is the momentum of stability when heeled to the given angle represented by *Fig.* D; action and re-action being equal, W a is the effort of the wind, or the force which holds the vessel in the given position, that is, a force acting at the same distance from the centre of motion as the weight of the vessel concentrated in the centre of gravity does from the same; that is to say, if it be a vertical force, it must be acting at such a distance from the line of support, but on the opposite side, that its weight, when multiplied into its distance from the line of support, will be equal to the weight of the ship multiplied into the distance of her old centre of gravity from the same.

When the vessel is upright, it is evident that no meta-centre exists; therefore, her stability in that position is nothing; but observe, that the instant she is acted upon by any force which inclines her in any degree, however small, her stability begins and continues to increase as she is heeled over, until it reaches its greatest extent; after which it diminishes in a similar manner, and at last vanishes when the non-existence of the meta-centre takes place, *i.e.* when the centre of gravity g is brought in the line of support. In E (*Plate* V. *Fig.* 109) we represent the vessel heeled still further over, so that her stability is now decreasing as the distance $g\,s$ is diminishing. The distance $g\,s$ (*Fig.* E) being less than $g\,s$ (*Fig.* D), a less force will sustain her in the position E; and it will be perceived, that as the points g and m come together after the vessel has passed her utmost degree of stiffness, so does the stability diminish; and the instant g passes over to the lee-side of the centre of immersion, the vessel upsets. If the centre of gravity of the ship had been higher up than the point g, as at I, she would have lost all her stability before coming to the position E. Hence the advantage of keeping the centre of gravity as low down in the vessel as possible, if we would desire the greatest degree of stability; for this will be increased at any given angle of inclination directly as the centre of gravity is lowered, and decreased directly as it is raised in the vessel.

It has been found, that when the centre of gravity is low (as when loaded with iron), the vessel is too stiff and laboursome in the sea, and apt to roll away the masts, if the greatest precaution be not used in hoisting proper sails; and that when loaded with a light cargo, without having a sufficient quantity of ballast, which causes the centre of gravity to be high above the surface of the water, the ship is so extremely tender that a proper quantity of sail cannot be spread, and the rolling oscillations are frightfully great and dangerous.

Having shewn the nature of stability in ships, and how it is affected by the position of the centre of gravity, I shall next consider how far it is affected by the length, breadth, depth, and form of the vessel.

Stability in regard to the Length.—The stability of ships, as respects their power to

carry sail, will be affected singly as their lengths, all other things remaining the same. Thus, if a vessel be twice as long as another of the same breadth and depth, she has twice the capacity of that other, and carrying twice the weight, will displace twice the quantity of water at the same depth; and her midship section being the same, and centres of gravity and immersion the same, the distance $g\,s$ will be the same; and having twice the weight acting at g', her stability will be twice that of the other; or if we make g' (*Fig.* 109) the centre of motion (as it probably will be when placed near the surface of the water), and consider the upward pressure of the fluid concentrated in the point I′, and acting on the lever S g, and as the ship of double the length displaces double the quantity of fluid, the upward pressure will be doubled; therefore she will have double the stability; and if three times the length, three times the stability; and so on in proportion as the length is increased.

Stability in regard to the Breadth.—The second proposition is, that the stiffness of ships will be as the squares of their breadths, *i. e.* that a vessel of twice the breadth of another of the same length and depth, will have four times the stability; three times the breadth, nine times the stability; and so on as the squares of the breadth, all other things remaining the same. Let A B (*Plate* VI. *Fig.* 110) be the surface of the water, figures F and G the transverse sections of two vessels of the same length and depth, heeled to the same angle of inclination, but the ship G of double the breadth of F. In the ship of double the breadth, the centre of gravity is four times the distance from the line of support, or the centre of support four times the distance from the centre of gravity; hence the resisting arm of the lever by which the upward pressure acts is increased four times. Therefore the meta-centric distance is also greater in the same proportion; consequently it is evident that a vessel of twice the breadth of another possesses four times the stability.

Stability in regard to the Height.—The effects produced by a difference of height are various. In most cases, additional height decreases the stability of the ship, but this depends entirely on how she is loaded, which of course regulates the position of the centre of gravity. If, for example, we have two vessels of the same length and breadth, but the one double the depth of the other, the centre of gravity of the one that is double the depth will be double the height, taking all things the same; and when she is heeled over to the same angle, the horizontal distance between the centre of gravity and the line of support will only be half that of the horizontal distance between the centre of gravity and line of support in the low vessel; therefore her stability will only be half that of the low vessel. But observe, that if the deep vessel be loaded with double the cargo, she will sink to double the depth in the water, or displace double the quantity of water; and if the cargoes are homogeneous, her centre of gravity will be immersed under the surface of the water, in the same proportion to her height as the centre of gravity of the low vessel is immersed in proportion to its height; and when heeled over to the same degree, the centre of gravity of the deep ship will only be half the distance from its line of support, that the centre of gravity of the shallow vessel is from its line of support. But the deep ship from having double the weight, or by displacing double the quantity of water, will have double the action on that point; and although her

meta-centre is only half the height of that of the shallow vessel, yet a double power, acting at half the length of lever, is equivalent to a single power acting at the whole length of lever; therefore, in this case, the deep vessel is equally stiff, when loaded in proportion to that depth.

Stability in regard to the Form of the Vessel.—With respect to the stability of ships as to the form of the bottom, it will be necessary, in the first place, to consider them as homogeneous, and then notice the difference which the form makes in regard to giving more room for stowing the cargo properly.

First, if a solid body, whose section is a square, have its centre of gravity in its centre of cavity, *i. e.* if it be homogeneous, such a body will not possess stability, whether partly or wholly immersed. But if its centre of gravity be the least distant from its centre of cavity, it will possess stability whether wholly or partly immersed, and it will endeavour to float with its centre of gravity below its centre of cavity. If a homogeneous body, whose transverse section is an equilateral triangle, float with its centre of gravity in a line with the surface of the water, it has no stability, but will float with any of its sides or corners uppermost. But observe, that it has stability if it sink so far as to immerse its centre of gravity in the water, and it will not remain in such a position as to keep its centre of gravity above water. If the triangular body have its centre of gravity below its centre of cavity, it will have stability. If an irregular-sided triangle be immersed in a fluid, it will have stability, whether its centre of gravity is in its centre of cavity or not, or whether its centre of gravity be even with the surface of the water or not, or whether it is wholly or partly immersed; and these arise from the positions which the centres of immersion and gravity assume, according to the angles to which the bodies are inclined, and their particular form. These conditions may be easily perceived by constructing the figures and finding the centre of immersion in the different cases.

After what has been said on the stability of a body whose transverse section is a square, and another whose transverse section is a triangle, we shall have little trouble in determining the best form of section to gain stability. The triangular body has the following advantage over the square body, *i. e.* the square body has no stability when its centre of gravity is in its centre of cavity; but the triangular body has stability, although its centre of gravity is in its centre of cavity, (except when it is an equilateral triangle floating with its centre of gravity in a line with the surface of the water); therefore it is to be preferred to the square body.

Suppose *Figs.* H and L (*Plate* VI. *Fig.* 111) to be the transverse sections of two vessels of the same length and breadth at the load-water line A B and A′ B′, both heeled to the same angle; let g and g' be their centres of gravity, i and i' their centres of immersion. Now when the body H is heeled over, a portion of its weather-side A O C is raised out of the water, and it depresses an equal portion D O B of the lee-side, and therefore the centre of immersion shifts towards the lee-side as to the point n, and the meta-centre at this angle is the point m. The body L also, when heeled over, raises a portion A′ O′ C′ of its side out of the water, but it depresses a greater portion of the lee-side D′ O′ B, or it displaces a greater quantity by the lee-side, as the portion D′ B′ e; but both bodies displace an equal quantity on each side of their lines of support $n\,m$ and $n'\,m'$; n being the

centre of displacement of the body, H and n' that of the body L; and the comparative stabilities are exactly as the height of their meta-centres above their centres of gravities are to one another, *i. e.* the stabilities of H to L as $g\,m$ to $g'\,m'$, or as $g\,s$ to $g'\,s'$, and as $g'\,m'$ is greater than $g\,m$, the body L has the greatest stability.

Having shewn clearly that a vessel which spreads out regularly to the top is stiffer than one whose sides are perpendicular, we may remark that the former would draw more water than the latter when loaded with the same cargo, and that if their cargoes be homogeneous, or the same quantity of heavy goods stowed in the bottom of each, the difference in the form of their transverse sections will not give the one any advantage over the other, in increasing the depth of their natural centres of gravity.

Farther, let it be observed that if it be found that the vessel H is sufficiently stiff, so as to carry away her masts before oversetting, which every ship should, and it is desired to have another vessel of the shape of *Fig.* L, and to possess the same stability; then it is evident that we would require to reduce the breadth at the load-water line, and increase the length a little, to give the same capacity. But we should consider well what alterations are made in these dimensions, as the stability will decrease faster than in the simple proportion of the breadth, for the stability of vessels similarly built increases as the squares of the breadth, and singly as their lengths.

After what has been said in respect to the form of the transverse section of the vessel in increasing the stability, I may observe that the form of the longitudinal section has an effect in allowing the ship to be properly loaded to the best advantage; for example, if a ship is very straight in the sheer, her cabins and forecastle are much lower down in her than if she had a proper sheer, and from being so low down, occupy a great part of the hold, which might otherwise be stowed with the cargo, which on this account is stowed high up in the middle of the hold; this raises her centre of gravity, and makes her crank. On the other hand, if she had a proper sheer, her cabin and forecastle would be raised higher out of the hold, and more of the cargo stowed under it; this would keep the centre of gravity low, and be of advantage on another account, inasmuch as it would raise the centre of cavity. Hence the advantage of giving the vessel a proper sheer, as tending to increase her stability, and also in allowing the cargo to be stowed more equally throughout her length, thereby having less effect in hogging, straining the hull, or destroying the form of the ship as originally built.

On the Application of the Theory.—It must have been observed, that without a knowledge of the height of the centre of gravity, it would have been impossible to determine the stability, and that we chose to fix that point higher up or lower down at pleasure. But before the theory could be applied to determine the stability of a real ship, the true height or station of that point, as it really existed, when she is loaded, upright, rigged, and ready for sea, would require to be known. The theory requires that the transverse section which we consider, should be a medium section of the whole vessel; now, as vessels differ so widely in their sections, not being regular bodies, but tapering towards the bow and stern by curving gradations, it becomes a point of nearly as much uncertainty to find the true shape and form of this mean transverse section, on which the position of the centre of immersion depends, as to find the centre of gravity. We might

easily ascertain the area of a section, which, if multiplied by the length of the ship, would produce her solid contents; but this would not answer the purpose, unless we could rely upon its being the true figure of the mean transverse section.

Having found the centre of gravity and the mean transverse section, we may then proceed to determine the stability of the vessel at any given angle of inclination. In the first place, a water-line is drawn across the section, and by the rule for finding the centre of gravity in an irregular surface, we ascertain the centre of displacement when the ship is upright and when inclined, and then the meta-centre; and taking the distance between the meta-centre and centre of gravity for radius, take the sine of the angle contained between the line of support and the vertical axis of the section, for the distance between the centre of gravity and the line of support (which is the length of the lever by which the stability acts). We ascertain, in the next place, the exact weight of the vessel, including the cargo, mast, sails, men, &c.; and putting W for this weight, and a for the distance between the centre of gravity and the line of support, $W \times a = S$, the stability of the vessel at the given angle of inclination. Now, a weight $w' = W$, at the same distance above the meta-centre as the centre of gravity is below it, would have the same leverage power to heel the vessel over as the weight of the vessel had to restore her to her upright position, *i. e.* the weight w' would overhang the line of support as far on the lee-side, as the weight W overhung it on the weather-side; therefore the vessel would be balanced on that line. Again, if $\frac{1}{2} w$ be suspended at twice the distance from the meta-centre to the centre of gravity, above the meta-centre, it will hold her to the inclination; and if this distance be tripled 1-3d, w will hold her to the inclination; and so on for any other height, the power being decreased as the lever by which it acts is increased, as shewn by *Fig.* 112, *Plate* VI. where g is the centre of gravity, I the centre of displacement, and m the meta-centre. Now, if W is acting at g, a weight w acting at n in the direction $n\,s$, would balance the ship at the given angle; but as W and w in this case are equal, and both acting as weights, the ship would sink deeper into the water, and her common centre of gravity would be raised. The wind on the sails is the inclining power, and for small inclinations it may be supposed to act at right angles to the mast. Suppose the mean action of the sails, or centre of effort, is at P, five times the distance $g\,m$ above the point m, which may be taken as the fulcrum; then as the weight W is to the distance $m\,h$, so is the power of the wind acting at P to the distance m P: We take the distance $m\,h$ in place of $m\,g$, because the weight of the ship is not acting at right angles to the line of the masts. Again, let us suppose that the power acts on the mast in the direction R Q, with a force at the point P equal to P T; the force P T, if applied in the direction P R, will be reduced in its effect as P R to P T. The use of the theory is evidently to find the proper quantity of sails which the vessel should carry at a given angle of inclination, or to determine the relative stability; but as it is impossible to calculate the true effect of the wind on the sails of a ship, it is of little use in practice. There are also many other circumstances connected with the action of a ship at sea, which on account of their minute and intricate form, and the irregular motions to which they are exposed, render the application of theoretic investigations extremely uncertain.

Being aware of this, I have thought it unnecessary to enter into any elaborate investigation of the subject, or give calculations of the stability of any ship. My chief object is to point out the method by which the comparative stability of vessels of dif- forms and dimensions may be ascertained, that we may have some idea of the effect of the form and dimensions of the ship, in making her stiff or crank at sea.

In the theoretical treatises on this subject, the displacement is generally given, as the first elements to be determined. As this is done by measuring the area of the water-lines, perhaps it will be more proper to make the reader acquainted with the nature of these and other lines, before directing his attention to the calculation for finding the displacement. In a subsequent part will be given a calculation for the displacement and centre of gravity of the steam-vessel, *Plate* XXIX.

It may be necessary to remark, that the preceding observations on the stability and side-stiffness of vessels have been confirmed by experiments made with models of ships of the same general form, but of different dimensions of length, breadth, and depth. Also three boxes of the same length were taken, the second being twice the breadth of the first, and of the same depth; the third, twice the depth, and the same breadth as the first; and also one three times the breadth of the first. The first was loaded with sand, and immersed in a cistern of water; a pin was stuck into its ends at the centre of gravity; a weight was then suspended over a pulley, the other end of the thread being fast to the mast, and in this way its utmost stability, and stability at any given angle, was found. The second box was then loaded with twice the weight of sand, which immersed it to the same depth, and its stability was found to be four times that of the first box, as it required four times the weight to incline it to the same angle; and in the same manner, the box of three times the breadth was found to have nine times the stability. The box of the same breadth as the first, but twice the depth, was loaded with twice the weight of sand, and required the same weight hung over the pulley to incline it to the same angle as the first.

On the Rolling Motion.—Having explained the laws of stability, the rolling motion will now be considered,—how far it is affected by the manner of loading, the action of the wind and waves on the ship and sails, and the form of her bottom. The principal agents which produce the rolling and pitching motions of ships at sea are four—two external and two internal. The two external are the wind and waves—the internal are the action of gravity on the ship concentrated in her centre of gravity, and the action of of the water on the cavity of the ship concentrated in the centre of immersion. The two latter, however, according to their position, more properly regulate these movements, than produce them. When a ship is upright in the water, and at rest, her centres of gravity and immersion are in the same vertical line; the whole weight the ship is equal to the vertical pressure of the water on her bottom, and each of these being concentrated in their respective centres, and exactly opposite, naturally destroy each other, and the vessel is quiescent. But if from some external cause, the ship be made to heel or cant over to one side, these two centres are no longer vertical to each other, but are inclined from their former position. They will remain so until the power

which inclines the vessel be removed, when the ship will resume her former vertical position, by the action of the fluid on that part of the cavity which overhangs the centre of gravity. Farther, if the power which heeled the vessel be suddenly removed, the action of the fluid and force of gravity will then throw her back to the upright position with an accelerated motion, thereby producing a momentum which will carry her past the vertical position, and make the centre of immersion again shift towards the weather-side of the centre of gravity. This is said to be the first roll of the vessel. Owing to the same cause, she will again be thrown back to the lee-side, and will thus continue to oscillate backwards and forwards, but gradually decreasing these oscillations until she at last become quiescent, with her centres of gravity and immersion vertical to each other as at first. The centre of motion on which the vessel vibrates when rolling, or the axis about which she turns, is supposed to pass through the centre of gravity of the ship when that is near the surface of the water. But it is evident that the centre of motion of a ship, when in the act of rolling or pitching, can have no fixed station, but be continually changing, as the centre of immersion and meta-centre are changing their places.

To simplify the demonstration, we may suppose the centre of motion to be in the centre of gravity, or on a level with that centre, but in the line of support, which is more correct. Now, suppose a ship to be in an upright position, and to have her centre of gravity and immersion at the same depth below the surface of the water, and that a wave impinges against one side, the top of the wave being above the common level of the water, or of the water at the other side of the vessel, and above the centre of motion or rotation (its impinging force being as its quantity and the square of the velocity with which it meets the ship's side*), this produces a momentum, by acting at a height above the centre of motion, which is proportionate, first, to the quantity—second, to the force with which it strikes the ship—and thirdly, to the height at which it strikes her above the centre of motion; hence this momentum of force throws the vessel over to the lee-side. Farther, as the pressure of a fluid is at its perpendicular height or depth, it follows, that while the wave is raised above the common level on the one side, there will be an additional vertical pressure on the bottom of the same side; and it is the combined effect of the former and the latter forces, the one acting horizontally, and the other vertically, that produces the first roll or heel to leeward. As before observed, however, the ship will not remain in this inclined position, for the lee-bilge will now be most deeply immersed; and the centre of immersion having shifted to the lee-side, and as the wave will now subside from the weather-side, and rise up to leeward, the vessel will return again with great force to the weather-side, and the weather-roll will always be quicker than the lee-roll. The rolling motion will be quicker, according as the centre of motion is farther under the surface, as the leverage power by which the wave acts will be increased; for it is obvious, that if the centre of motion be as high as the top of the wave, it will then have no leverage power to cant or heel the vessel over, and the only force left will be the increased pressure on the bottom of the same side, or, which is the same thing, the centre of displacement will shift to the side on which

* The consideration of the impulsive force of the wave on the ship's side may however be disregarded.

the wave has risen. From this we infer, that the weather-roll will be performed in less time than the lee-roll. But it must be observed, that if the waves continue to succeed each other in succession, the difference between the times of the lee and weather rolls will be greatly diminished. The weather-roll, however, will always be the quickest, for although it is certain that the action and re-action of the waves will become nearly equal, their effect on the ship will not be the same, because she will acquire a motion in the direction of the waves. The velocity, therefore, with which the ship rolls to windward, will be greater than that with which she rolls to leeward, as the lee-roll will be lessened in proportion to the side-motion acquired by the heaving of the sea; and the rolling both ways will be reduced, for the same reason.

Many are of opinion, that a vessel will not acquire a side-motion, or drift to leeward, by the action of the waves alone; but according to Sir Isaac Newton, a wave whose breadth is about $3\frac{1}{2}$ feet, will advance through a space of $3\frac{1}{3}$ feet in a second of time, or nearly two miles per hour. Greater or lesser waves will be increased or diminished in velocity, in the sub-duplicate ratio of their breadth, or nearly so; and the ascent and descent is of a circular nature, and in the direction of the waves. Now this last is sufficient to produce the side-motion of the ship. It is not affirmed that the side-motion of the ship will be equal to the run of the waves, but they will affect her so as to cause her to move in their direction; for if we place a piece of wood in still water, and then agitate its surface so as to produce waves, these will be found to have the effect of driving the piece of wood in their direction.

The rolling motion of the ship, independent of the action of the wind, having been explained, let us next consider the effect produced when the action of the wind on the sails and on the upper-works of the vessel is taken into account; and we shall allow the motion of the waves to be the same, and to produce the same effect as before.

It is certain that the action of the wind upon the upper-works and sails of a ship will tend to make her heel to one side in still water, that it will either retard or accelerate the rolling motion produced by the action of the waves. In order to point out the joint effect of these two powers, the wind and waves, it will be necessary to notice the velocity of the wind, the height of the sails on the masts, and the depth of the ship in the water.

If a ship rolling by the action of the waves, as before explained, be acted upon by a strong breeze of wind in the same direction as the run of the waves, then it is evident she will heel farther over to leeward, and less to windward, in proportion to the quantity of sail, and the height at which they are set on the masts; and by this action of the sails, the rolling motion will be much diminished, and the vessel in less danger of being boarded by the sea on the weather-side.

Suppose a ship, loaded to the depth of 16 feet, have her centre of motion about the surface of the water; let the keel, which is 16 feet under the surface, vibrate with a velocity of 8 feet per second; and suppose the centre of gravity of a sail to be 64 feet above the surface of the water, *i. e.* equal to four times the distance of the keel from the centre of motion; it is evident that the vibrations of the keel and sail will be performed in the same time, and that the velocity of the sail, by a roll of the ship, will

be four times that of the keel in the opposite direction; so that if the keel describe an arc of 8 feet, or pass through 8 feet of space, the centre of gravity of the sail will move through a space of 32 feet in the same time.

Again, let us suppose the velocity of the wind to be 48 feet per second, and the motion at the keel and centre of gravity of the sail the same as before; it is certain, that during the lee-roll the wind will only act upon the sail with a velocity of 16 feet per second, because it will be lessened in its effect by as much as the velocity of the sail in the same direction. Thus, the velocity of the wind 48 − velocity of sail $32 = 16$, the action of the wind on the sail during the lee-roll. Hence in this case the momentum of the lee-roll is only increased 1-3d of the velocity of the wind; but from the motion of the sail compared to that of the keel, the weather-roll will be retarded by the whole velocity of the wind plus the velocity of the sail to windward.

In this example, the action of the wind on the sail in the lee-roll may be estimated equal to a breeze of 11 miles per hour (about 16 feet per second), and the action of the wind on the sail in the weather-roll 40 miles per hour (about 64 feet per second), which is about 2-3ds the velocity of a strong gale.

Again: Suppose the rolling motion of the ship at the keel, exclusive of the action of the wind, to be only 4 feet per second, the motion of the sail will then be 16 feet per second; allowing the velocity of the wind to be the same as before (48 feet per second), the action of the wind on the sails during the lee-roll will be $48 - 16 = 32$, and on the sail during the weather-roll $48 + 8 = 56$ at a medium. Now it appears that the momentum of the lee-roll is increased to 32; it is thus double what it was before, yet from the nature of stability, if the ship be of the common construction, she may perhaps go a foot farther over to leeward than before, but not twice as far. Again, for the weather-roll, when the ship is heeled to leeward, she endeavours to throw herself back to windward with the same velocity as she went to leeward; but this cannot take place, because she would be retarded by the whole action of the wind, increased by the motion of the sail, and this would be 16 feet per second, and make the retardation to the weather-roll 64 feet per second, with which she would not roll over so far to windward as by the action of the lee-roll alone, by 1 foot, making a difference in her rolling from one side of the axis to the other, of 2 feet. The sail, however, will not move with a velocity of 16 feet to windward, but with a maximum velocity of 8 feet per second; therefore we must add 8 feet to the velocity of the wind for the mean retardation to the sail during the weather-roll. When we consider the rolling motion before the action of the wind commenced, it is evident that the ship will go equally far over on each side of her former vertical axis when upright. It is evident, also, that if the wind has been sufficient to make her heel or roll over one foot farther to leeward than before, it would prevent her from rolling so far to windward by 1 foot; therefore there would be a difference of 2 feet between the lee and weather-rolls, measured from the vertical position.

From these observations, it is evident that the rolling motion of a ship may be considerably retarded by the manner of loading, so as to regulate the position of the centre of gravity. If the centre of gravity is placed low in the vessel, her rolling motion will

be quick and short, and very prejudicial to the masts; but if the centre of gravity be high in the ship, her rolls will be long and slow. It is in the coming back, or weather-roll, that the masts are most seriously injured, or carried away; and it has been seen that the greater the velocity of the sail, compared with that of the keel, the less the vessel will roll. The safety which the masts derive from a high sail is not from any diminution of the strain on them by the sail; for to prevent the vessel from rolling to windward, it is the same whether the sail is set high or low on the masts; for to produce the same effect, their momenta of reaction must be the same, *i. e.* their surfaces, multiplied by their heights and their velocities, must be equal. The advantage of a high sail is, that it not only reduces the rolling and tugging motion, but is more equal in the wind than a low sail, and keeps a more regular strain on the masts; whereas a low sail is sometimes a little becalmed when the vessel is in the trough of the sea, and is again acted upon as by impulse when the vessel rises to the top of the succeeding wave. And observe, that the same statical momentum of sail (*i. e.* its surface multiplied by its height above the centre of motion) will produce different effects in reducing the rolling motion, according to the height at which it is placed. For example, suppose the surface of a sail, set at the height of 20 feet, is 200, its statical momentum is $20 \times 200 = 4000$. Again, suppose a sail, set at the height of 40 feet, and having a surface of 100, then its statical momenta is $10 \times 40 = 4000$. Now the velocities of these sails is as their height: that of the high sail will be double that of the low one; therefore it will recede from the action of the wind in the lee-roll with double the velocity, and thereby reduce its effect; but it will also come against the wind in the weather-roll with double the velocity that the low sail will do, and thereby double the effect of the wind in reducing the weather-roll. Suppose a ship rolling by the action of the waves with a velocity of 4 feet per second, at the distance of 10 feet from the centre of motion, and the wind blowing at a velocity of 32 feet per second; required, the height of a sail to have no action on the lee-roll? Then $32 \div 4 = 8$, and $8 \times 10 = 80$ feet, the height; and if it be set at any height above this, it will retard the lee-roll by as much as it moves faster than the wind. It is evident, therefore, that a very small sail set high upon the masts will reduce the rolling motions of the ship very considerably.

The rolling motion of ships at sea can never be prevented, though at the same time it may be greatly lessened by a particular construction of the bottom, the stowage of the cargo, and the quantity and height at which the sails are set. It is only by a due attention to these and similar particulars that their good performance can be estimated. The two latter fall particularly under the notice of the captain. Some are of opinion that the rolling and pitching motions are regulated entirely by the disposition of the cargo; but the manner in which the sails are set, and the particular construction of the ship, have their due effect in making her easy in the sea.

It should be observed, that in many cases it is almost impracticable to stow to the best advantage the cargoes which vessels are sometimes employed to carry, so as to bring the centre of gravity to the most proper place. Some vessels, from their particular construction, are much quicker in their rolling motions than others: Some are

very difficult to trim, and require the greatest attention in stowing the cargo; for if the heavy part of it be placed at all too high in the ship, her rolls will be so long and heavy, that she will run a risk of oversetting, or throwing every moveable article to leeward. On the other hand, if the weighty part of the cargo be placed too low, she will be equally quick in rolling, and apt to carry away her masts; besides, she will strain her upper-works, and be in danger of becoming leaky. Hence the commanders of those vessels which are awkward and laboursome at sea cannot be altogether accountable for the damage sustained by the masts, sails, rigging, &c., particularly when they have been obliged to take in a heavy and unwieldy cargo, without having time to pay attention either to the properties of their ship, or to the dangers of the intended passage.

What has been said as to the effect of a high sail in preventing the vessel from rolling, applies equally to the pitching motion.

It is well known to all seafaring persons that a small sail set high on the vessel will have much more effect in preventing the rolling, than a large sail set low; and the reason that is generally given for the cause of this effect is, that from the sail being high, it is not only more constant in the wind, but acts with a greater leverage power on the vessel. But this is ascribing the effect to a wrong cause, for it is evident that in many cases a sail may be as freely exposed to the wind at the height of 30 feet above the decks as at 60 feet, and that a low sail, from having a larger surface, will produce the same effect in heeling the vessel over in smooth water, as a small sail set high. When we consider the different velocities with which the low and high sails move by the rolling of the ship from the action of the waves, we find out the true reason; for the velocities of the sails being as their height, the low sail will move slowly away from the wind by the lee-roll, and not increase its effect much by coming against it in the weather-roll; whereas the high sail may even move faster to leeward than the velocity of the wind during the lee-roll, so that the wind cannot increase it—the sail will rather suffer a resistance from the air on its lee-side, which will prevent the vessel from rolling so much to leeward as before. When the vessel inclines to roll to windward, the velocity of the sail being great, increases the action of the wind, so that the weather-roll would be much retarded from what it would be were the sail set low.

It is well known that a vessel will go much more easily along on the edge of the sea with close-reefed topsails set over her reefed courses, than with the topsails taken in, and a much greater portion of canvas set on the lower masts.

If we observe a steam-boat and another vessel sailing along on the edge of the sea, the sailing vessel will appear to go steadily along, inclining a little, and seeming to have a slight motion, while the steam-vessel will be rolling and tumbling about. To lessen this unpleasant motion, I have often advised the captains of steam-vessels to set a small sail as high as possible, to prevent their vessels from rolling when going with the sea on their beam.

The position of the centre of gravity has not only its effect on the rolling motion, but also the manner of stowing the heavy parts of the cargo, as regards the placing them nearer the sides of the vessel, and it is evident that this may be varied, and the centre of

gravity still remain at the same height. It is a law of revolving or rolling bodies, that they have their motion increased or reduced according as the heavy parts of which they are composed are nearer or farther from the centre of motion. Thus, if a vessel have heavy goods stowed in the middle of her breadth, and the light goods towards the sides, her rolling motion will be quick, but at the same time easily retarded by the power of the wind on the sails; whereas, if the light goods are put in the middle, and the heavy towards the sides, her motion, although slower, will not be easily retarded, but she will require a greater portion of sail to keep her equally steady and easy in the sea, than when the weighty parts of the cargo are stowed in the middle, or properly distributed throughout her breadth. We shall recur to this in the course of our remarks on the pitching motion.

On the Form of the Bottom, to prevent Rolling.

Having explained the nature of the rolling motion, and shewn how it is affected by the position of the centre of gravity, the action of the sails, and the manner of loading, I shall next point out what forms appear best adapted, from principle and experience, to prevent heavy rolling.

In the first place, let us observe that the surfaces of floating bodies, like all others, are formed by straight or curved lines, or by both; that a curved line, having one common centre, must either be a circle or a segment of a circle; and that all circular bodies will meet with less resistance, when revolving in a fluid, than those of any other form.

Let us suppose a homogeneous cylinder to be immersed in a fluid, with its axis parallel to the surface: Its centre of gravity is in its axis; therefore, as far as regards the rolling motion, no meta-centre can exist by any change of position, because the centre of displacement will always be found in the vertical line which passes up through the centre of gravity of the cylinder. In this way, circular bodies having their centres of gravity so situated, will, when immersed in a fluid, revolve on this imaginary axis with any degree of velocity; but their motion will be uniformly retarded, until they are at last brought to a state of rest by the friction of the water on their surface, in exactly the same manner as an equally balanced cylinder, when revolving on its axis in the open air. If the cylinder is not homogeneous, but has its centre of gravity eccentrically situated, a meta-centre will be formed, and its motion will not be uniform, for the heaviest side will preponderate, and after a few revolutions the cylinder will come to a state of rest, with its centre of gravity vertical to its centre of suspension or motion, if the cylinder is revolving on an axis in the air; and if revolving in a fluid, with its centre of oscillation vertical to its centre of gravity.

It is evident that circular bodies will turn or roll quicker than any other, because the pressure of the fluid being always perpendicular to the surface on which it acts, their line of direction always points to the centre of the circular body, which on this account must become the centre of motion. As there are no direct resisting parts on the circumference of a circle to its oscillatory motions, the only resistance to the same arises from the small friction which the particles of water are known to possess, acting at tangents to their point of contact.

From these considerations, it is certain that all ships or boats having a long round bottom will be more inclined to roll than if they were of any other form, independent of any degree of stability that they may possess. They will also be more difficult to trim with their cargoes, than those vessels that have a better form for preventing heavy rolling. Many shipbuilders have overlooked these facts, or at least have not paid attention to their effects; for they have formed the midship sections of their vessels of a circular shape, thinking, with the mathematical connoisseurs, that (as it is known that the area of a circle is the greatest that can be bounded by the same length of circumference), it must be the proper form for the bottom of a vessel, as it will give the greatest cavity with the least surface for the friction of the water. This would certainly be correct, did not the bad effects of such a form in increasing the rolling, counteract the small advantage of a diminution of the friction of the water to the sailing motion of the ship. Some shipbuilders carry this fallacious notion still farther, for it is not uncommon to see vessels with little or no inward hollow in any of their transverse sections. A (*Fig.* 113, *Plate* VI.) represents the midship section of a vessel on the round-bottomed construction; B a section at the after part of the entrance; and C a section at the fore part of the run, from which it may easily be confirmed that such a vessel would roll very much. But below these, there are placed the sections of a vessel on a different principle; D the midship section, E a section at the after part of the entrance, and F a section in the run. The advantage of this construction in preventing the rolling must be evident from the slightest consideration; but it will be necessary to notice that the sections of this vessel are the most proper for another reason, *i. e.* in allowing the fore-and-aft curves to be of the form best calculated for opening and closing the fluid in the most uniform manner, as will be fully considered hereafter.

In order to prevent the rolling motion from becoming too great, the vessel should have a good breadth in the bottom, and the floor-timbers betwixt the sir-marks should be about 3-5ths of the breadth of the midship frame, having a rising of one inch to the foot of their length, and be made a little hollow towards the keel, making the garboard-strake stand with a little more cant or elevation than the rest of the floor; a good hollow in the lower part of the run is also requisite. The straight part of the side from the lower to the upper height of breadth should scale out about $\frac{1}{4}$ inch to a foot for large vessels; and for small vessels, for the coasting trade, it might be $\frac{1}{2}$ inch to a foot. The keel should likewise be two inches broader at the bottom than at the garboard-strake, and dressed with a small hollow, which will increase the resistance when the vessel is rolling, with a power in proportion to its depth under the surface of the water; this will also retard the vessel from going to leeward when sailing upon a wind. The bottom being formed in this manner, it is easy to conceive, that as the flat and hollow parts diverge from the convex curve of the bilge, they must become powerful resisting parts in the plane of the rolling motion. With these practical remarks, I now conclude the description of the rolling motion.

On the Pitching Motion.

The pitching, like the rolling motion, is different in all kinds of vessels, according to their particular construction and the manner in which the cargo is stowed; but in general, it is not so much affected by the action of the sails.

It is an admitted principle, that floating bodies are held in equilibrio according to the arrangements of their various parts, and the action of the fluid on the external surface of the body; and from the nature of fluids, the body is as it were balanced upon one single point in every position which it can possibly assume. If the body be made to ascend and descend alternately at the two extremities, a certain point in the middle of these two extremes will become their common centre of motion; and if it be allowed to vibrate freely, the centre of motion will be the centre of gravity of the body. Now, we may suppose a ship to vibrate upon, or turn round a horizontal axis passing through her centre of gravity.

The rising and falling of the bow and stern of the ship by the action of the waves, is termed the pitching motion, the extent of which will be in proportion to the magnitude of the waves and the disposition of the heavy parts of the cargo; for every material on board will be moved with different velocities, according to their distance from the centre of motion or middle of the ship, and their effect as their momentum. In consequence of this, every article which is moved from one part of the ship to another will produce different effects, let the distance it is transferred be ever so small.

Suppose, for example, that all the weighty parts of a cargo are placed in the middle of the ship, then both principle and experience prove, that she will be very quick in her pitching motion; for her ends being light, are easily lifted, and of course would rise and fall with the impulse of every little wave, causing a quick tugging motion in the sails, which would strain both masts, rigging, and hull, and she would also be much retarded in her sailing.

If the weighty parts of the cargo were placed near the ends of the vessel, her motion would be slow, but long and great, and strain the masts and hull very much; this would be dangerous, inasmuch as the vessel might not rise in time to meet the next wave, which would break over the bow or stern, and perhaps wash every thing off the deck.

It will readily be admitted, that if these two extremes are avoided, and the heaviest parts of the cargo laid near the middle, and the weight gradually diminished towards the ends of the ship, she will then be less quick in her motion than if the weight were entirely placed in the middle, and also not send so deep as if the weight were laid nearer the ends; the hull and rigging would be less strained, and the vessel move more swiftly through the water.

As some are of opinion, that whether the heavy parts of the cargo are placed in the middle or near the ends of the ship, provided she is on the same draft of water fore-and-aft, is of little consequence, as far as regards a vessel's pitching, it may be proper to shew that the assertion is at varince both with principle and experience. The only difference between the rolling and pitching motions is, that the one takes place when the waves are running in the length direction of the ship, and the other when running in a transverse direction to her length, or when the vessel is sailing in a transverse course to the direction of the run of the waves.

In demonstrating the rolling motion, notice was not only taken of the increased pressure on the side or bottom of the ship which was most deeply immersed, as producing the force which caused her to roll, but also of the impulse of the waves on the side, as producing a momentum to throw the vessel over, by acting above the centre of motion. In the pitching motion, it will be sufficient if we consider it to be produced by the increased hydrostatic pressure at each end of the vessel alternately. Let us imagine a vessel at rest, and that while in this state a wave approaches her bow; then let us suppose her not to rise gradually with the swell of the wave, as she would immediately begin to do, but that she seems not to be affected until the top of the wave has reached her stern or the luff of the bow. If she were to remain in her former level position, it is evident that at this moment there would be an increased vertical pressure on the bow, as it would be two, three, or four feet deeper immersed than before, according to the size of the wave; but as the bow or weight of the vessel, before the centre of motion, was in equilibrio with the vertical pressure of the fluid before the wave approached her, and as she could not counteract the increased vertical pressure caused by the wave, her bow would rise up so far as to reduce the increased pressure to the equilibrium with her weight, and at this moment she would be off her former level. In raising up the bow, a momentum is produced, which will throw it up beyond the degree which would be necessary to equalize the vertical pressure of the fluid and weight of the bow; and the effect of this momentum would cause the vessel to turn as it were upon a horizontal transverse axis passing through her middle or centre of gravity; consequently her stern end would descend with a momentum, and immerse itself deeper than when lying in smooth water. The vertical pressure, therefore, on the stern, would be also increased, and this would push the stern end up with a momentum. We must also notice that the wave would now have left the bow and approached the stern end; it would therefore increase the rise of the stern, while the bow would be descending with considerable velocity, and its momentum would cause it to descend until it was again counteracted by an increased vertical pressure, which must be equal to the weight of the bow multiplied by the velocity with which it descended, adding the momentum of the stern end in the ascending direction, which is its weight multiplied by the velocity with which it ascended. Upon the action of the succeeding wave on the bow, it would again be raised up above the common level, and the stern would again descend below it; and so on continually, while the sea continued to run in the same direction.

Let the weight of the bow be represented by W, which is placed say 40 feet from the middle of the ship's length; then its momentum is $W \times 40 = 40$ W. Let the weight of the stern be represented by w at the distance of 60 feet from the centre; then the momentum of the stern end is $w \times 60 = 60\,w$. But the momentum of the stern end must be equal to the momentum of the bow; therefore $60\,w = 40$ W. Now the velocities with which the weights W and w move, are as their respective distances from the centre of motion, and their momenta as their weight multiplied by the velocity with which they move, which is their distance from the centre of motion. The bow will ascend and descend with a momentum $= 40$ W, and the stern end will descend or ascend with the momentum $60\,w$. Now the resistance to the bow when descending must

be such as to equalize its momentum. To do this, it must be so far immersed that the pressure of the water is increased equal to what the momentum of the bow is by its velocity; therefore the bow will be much farther immersed before it is counteracted by the water, than it would require to be if the ship were lying at rest. The same thing takes place at the stern of the ship.

If W be placed at 20 feet before the centre of motion, w would also require to be placed at the distance of 30 feet abaft the centre of motion, and in this case the momentum of the bow would only be one half of what it was before; therefore it would neither rise nor fall with the same force as formerly, upon the wave leaving the bow, and the same would be the case with the stern; for as the momentum of the bow is now only $\frac{1}{2}$ 40 W, and that of the stern $\frac{1}{2}$ 60 w, the bow could only rise half as far above the necessary hydrostatic depth of immersion required for its equilibrium of rest that it did before. It would only descend to half the depth below the necessary hydrostatic depth of immersion required for its equilibrium of rest; and the same might be said of the stern, the whole momentum of the pitching motion in the first case being $40\,W + 60\,w$, and in the second, $20\,W + 30\,w$. It is evident, that as the momentum is reduced one half in the second case, the vessel will rise more easily to the sea, as she will rise quicker, but not so far; neither will she send or dive so far into it, by one half, with the same rise of wave. It is also evident, that as the weights W and w are the same in both cases, the ship will draw the same water; and as they are moved from the two ends of the ship in the same proportion, she will draw the same water at the bow and stern as before, although she will now be much easier in the sea, and not pitch or send so much as formerly. It is hardly necessary to notice, that if the greatest part of the cargo be placed in the middle of the ship, her pitching motion will be quick and tugging, and prevent her from going fast through the water; for, as we formerly observed, the more steadily a vessel goes along, the more uniformly will she divide and close the water, and of course sail faster. The wind will also act with more uniformity on the sails.

It has also been found by experience, that many laboursome vessels have been much eased in their pitching and heavy sending motions, by removing some weighty articles, such as the anchors or part of the cables, &c. from the bow nearer to the middle of the ship.

On the Form of the Ship, to prevent heavy Pitching.

I shall now proceed to take notice of that form of the ship which tends to prevent as much as possible the pitching motion. In the first place, it may be mentioned, that those forms which are the best calculated to increase the stability of the ship, are the best for retarding any dangerous extent of the rolling or pitching motion; as the same principles which regulate the stability, equally affect the rolling and pitching motion. A narrow bottom spreading regularly out to the surface of the water, gives the greatest stability in all common cases, and therefore, for the pitching motion, the stem and stern part of the ship should rake outwards. We may illustrate the advantage obtained by this construction in the following manner:—

Let us suppose two vessels, the one having her bow quite upright above the com-

mon line of floatation, and the other having a regular rake or inclination outwards above the same; it must be evident, then, that on these two vessels being subjected to the pitching motion, the vessel with the raking bow will increase her resistance faster than the other, inasmuch as she will bring her centre of immersion farther out towards the bow than the upright vessel; or—what is the same thing, and will perhaps be more easily understood by the reader—we may take the distance between the masts of the vessels to the bow on the water-line for the resisting arm of the lever, and suppose the mast to be the lever by which the bow is depressed; then it is evident, that the vessel with the raking bow will lengthen the distance very fast as the bow descends, while the other will not lengthen it near so much in coming down to the same extent, and of course she will dive deeper into the water.

From the vessel having a regular rake of the bow, she will rise and fall more easily in the sea; she will ride safer at anchor in a gale, and not be so easily put out of trim as an upright-bowed vessel. From possessing these advantages, she will sail better on the average, and be equally dry and safe, although not so full in the bow; she will likewise be stronger, because, from the curvature of the bow being less quick than the others, the planks will be less strained in bending, which again will make her more easily planked. The same may almost be said of the advantage of giving the stern end a spreading form above the line of floatation, up to such a height above the water as the vessel would dip when pitching. It may appear that the raking-out of the bow would allow the upward pressure of the fluid to act more powerfully in throwing up the vessel in pitching, but as far as my experience at sea in differently-formed vessels enabled me to observe, I never found this to have that effect; for several ships of that description in which I have sailed were remarkably easy in their pitching motions.

In consequence of what has been stated, it may be safely affirmed, that to make a vessel go easily in the sea, the midship bottom or floor must be of a regular length, rising gradually towards the entrance and run, which again must be duly proportioned to each other. The bow, particularly in vessels intended for fast sailing, should rake regularly out, its horizontal curvature continually increasing towards the top, so as to form a flat cove or hollow in the vertical direction, at the luff of the bow; this tends to make the vessel very dry forward, as it throws the spray outward, instead of allowing it to be continually breaking over the bow of the vessel, which is the case with those whose bows do not rake or flange outwards. The stern and buttocks should also be carefully adjusted; the run abaft should be sharp, but the vessel should have a good buttock at the water's edge.

On the Proportion of Length, Breadth, and Depth of Merchant Vessels.

While so many theories and speculative schemes have been proposed to improve the construction of ships of war, it is not surprising that something of the same spirit should have diffused itself among persons connected with the mercantile marine of this country. Unfortunately, they are generally brought forward by those who do not possess a thorough knowledge of the principles of shipbuilding, and whose practical information is very defective. It has been suggested by some individuals, to diminish the

breadth dimension of sailing vessels, that they might suffer less resistance in passing through the water. So little acquainted with the principles of stability are many of those projectors, that they have thought, by taking three or four feet from off the breadth, and adding it to the length (which is equivalent to taking five or six feet off the breadth and keeping the length as before), the vessel would be equally stiff, and consequently, the resistance being less, the vessel would sail much faster; in this way, throwing out of view her working properties. Experience proves that this is not the case, and that there is a certain proportion of breadth to length, or length to breadth, according to the peculiar rigg, beyond which any further extension is not only useless, but dangerous. By taking from the breadth and adding to the length, the stability is decreased as the squares of the quantity diminished, and only increased singly as the quantity added to the length. By their proposition, the stability is decreased, the friction increased, and the vessel being unable to support a proper spread of canvas, is deprived of the full power of the sails: or, from being easily heeled over, presents an unfair part of her bottom to the action of the fluid, and is therefore more opposed by it. Had a small reduction of breadth been proposed, it might perhaps in some cases have been attended with advantage. Steam-boats, which are chiefly propelled by a force independent of the action of the wind, are of a great length in proportion to their breadth; and for such vessels, this long narrow construction is found to answer best for giving sufficient room for passengers. But sailing vessels must have sufficient breadth of beam, or they will not stand up. The best proportion of length and breadth of sailing vessels has never been solved by theoretical knowledge. In general, merchant vessels are a little varied in their principal dimensions, according to the particular trade for which they are intended, and thus naturally form separate classes. Among the vessels of each class, there may be a little variation. The first or principal variation observed in the dimensions of merchant ships, and which is so general, and to such an extent, as to be sufficient to distinguish them into classes, is absolutely necessary.

We should not be surprised to find a variation in the proportions of merchant vessels, when we consider that there has never been any established rule given for these dimensions, and that they are built by persons who are rivals in trade, and endeavour to keep their principles to themselves, if they think them superior to their neighbours. Vessels are sometimes built by persons who have had little experience, and who cannot be supposed to know exactly what would be the most suitable proportions. But it has been observed that some of them have given their vessels excellent proportions, and have been able to do so by examining into the character and dimensions of ships which have been built at different places, and then taking a medium from the dimensions of a number of vessels of the same class as their intended vessel, which is the best and safest method that can be resorted to in order to discover the just proportions of the different classes of shipping.

Before any rules are offered for proportioning these dimensions to each other, I shall first submit to the reader the following dimensions and proportions of breadth and length of a number of regular built merchant vessels of the different classes of sloops, smacks, schooners, brigs, and ships, which have been found to answer well, with the exception of some extreme cases, which are mentioned in the column of remarks:—

TABLE, shewing the General Proportion of Length, Breadth, and Depth of the different Classes and Sizes of Merchant Ships; also the Parts of 100 which the Breadth bears to the Length; and thus making the Length of all the Vessels the same, their Proportional Breadth is shewn by the Figures in the Sixth Column.

Classes, and Ships' Names.	Tonnage.	Length.		Breadth.		Depth.		Proportion of Breadth to Length, 100 the Denominator.	REMARKS.
		Feet.	In.	Feet.	In.	Feet.	In.		
Sloops.—Bee, - - -	53.24	47	0	16	5	8	0	34.8	
Margaret, - - -	63.26	50	0	17	4	9	0	34.8	Built by P. Hedderwick.
Packet.—Countess of Chichester, -	100.6	59	6	20	0	10	10	33.6	Formerly on the Holyhead station.
Proposed dimensions,	112.31	61	6	20	10	11	0	32.2	From a plan by Mr. Sainty. *
Ditto ditto,	102.70	62	3	19	6	10	6	31.3	Do. do. by Sir R. Seppings. *
Ditto ditto,	121.71	63	6	21	3	11	6	33.2	Do. do. by P. Hedderwick. *
Smacks.—Regent, Nor. Lt-House tender,	142.27	66	0	22	7	11	6	34.2	This vessel stands well up to her canvas, and sails fast.
Courier, - - -	142.90	68	0	22	2	11	6	31.3	Thought a fair proportion.
Matchless—Leith & London, -	170.25	71	0	23	9	12	0	33.4	Built at Bridport by Mr. Good.
Edinburgh Castle—ditto ditto, -	190.21	75	0	24	4	12	6	32.3	Built at Topsham by Mr. Davy—Plan by P. H.
Royal Sovereign—ditto ditto, -	204.46	78	9	24	6	12	9	32.0	Built at Leith by Messrs. R. Menzies and Son.
Venus—ditto ditto,	173.42	70	0	24	3	12	6	34.7	Too short for her breadth. Did not answer; was lengthened.
Ditto, after being lengthened, -	208.70	81	3	24	3	-	-	29.10	Answered better than before.
Schooners.—Charlotte,	101.69	62	0	19	6	12	0	31.5	
Glasgow—Leith & Hamburgh, -	155.44	72	0	22	4	13	6	31.0	Built at Leith by Messrs. T. Morton & Co.—Plan by P. H.
Brigs.—Down Castle,	149.32	72	0	21	10	14	0	30.0	
Blucher, - - -	158.52	72	0	22	7	14	7	31.4	Thought a broad ship. She sailed fast.
Amazon, - - -	196.87	82	0	23	4	15	6	28.5	Built at Leith by Mr. G. H. Anderson.
Mary, - - - -	205.15	83	6	23	7	15	6	28.3	Built at Leith by Messrs. L. Rose & Son.
Hope, - - - -	219.18	85	6	24	1	14	9	28.2	
——— - - -	254.51	92	6	24	10	17	0	26.11	Too narrow; very crank.
William Young, -	303.88	94	7	27	0	18	10	28.6	A very fast vessel—Plan by P. H.
Ships.—Brilliant, - -	322.82	96	4	27	6	19	0	28.6	Thought to be a broad vessel. Fast sailer.
Mary, - - - -	368.0	102	6	28	6	19	0	27.9	
Arcturus, - - -	370.34	103	8	28	2	20	0	27.2	Built at Leith by Messrs. Sime & Ranken.
Clyde, - - - -	454.40	105	0	31	6	21	3	30.0	A very broad ship.
Amazon, - - -	443.28	109	0	30	3	20	0	27.9	Built at Greenock. A good proportion.
——— - - -	452.63	116	0	29	5	20	0	25.4½	Narrow. A crank ship.
Albion, - - - -	505.66	119	0	30	9	23	0	25.10	Thought rather deep.
Severn, - - - -	567.35	116	0	33	4	22	2	28.8	A broad ship. Built in Calcutta by J. Horsburgh, Esq.
Clydesdale, - - -	598.43	126	0	32	6	-	-	25.9	Built at Greenock by Mr. Steel.
East India vessels,	818.0	146	0	36	0	21	3	24.7	Considered narrow vessels.
East India vessels,	1000.0	159	0	38	0	21	4	24.0	Considered narrow vessels.
East India vessels,	1257.0	165	0	42	0	23	6	25.4	Considered in a good proportion.

* *Vide* Fifth Report of Select Committee of the House of Commons on the Holyhead Mails and Packets, 1819.

Having inspected this Table of Dimensions, we observe, that small one-masted vessels, such as sloops and packets, have their breadth, on the average, fully one-third of their length; that smacks of about 170 or 180 tons are in breadth one-third of their length, being in the ratio of 33.5 to 100; that schooners are not quite so broad in proportion to their length, being in the ratio of 31.0 to 100; that brigs are a little narrower than schooners, being in the ratio of 29.0 to 100; and that three-masted vessels may be taken on the average in the ratio of 27.0 to 100. These are the mean proportions of the different classes; but we must observe that there is not only a decrease in the proportional breadth of the five classes of shipping given in the Table, as therein distinguished, but also, that as the ships, even in the same class, increase in size, they are diminished in breadth in proportion to their lengths.

Thus the	Sloop Margaret, of about	60	tons, has her breadth to length as	34.8 to 100
„	Smack Regent, - -	142	„ „ „ „ „	34.2 to 100
„	Smack Matchless, -	170	„ „ „ „ „	33.4 to 100
„	Smack Royal Sovereign,	204	„ „ „ „ „	32.0 to 100
„	Schooner Charlotte, -	101	„ „ „ „ „	31.5 to 100
„	Schooner Glasgow, -	155	„ „ „ „ „	31.0 to 100
„	Brig Down Castle, -	149	„ „ „ „ „	30.0 to 100
„	Brig William Young,	303	„ „ „ „ „	28.6 to 100
„	Ship Mary, - - -	368	„ „ „ „ „	27.9 to 100
„	Ship Albion, - - -	505	„ „ „ „ „	25.10 to 100

Now, as these vessels are considered to be of the best proportions of breadth to length, they have been taken as the data from which the following Table is calculated, of the length, breadth, and depth of the different classes of shipping, from the size of boats, up to a ship of about 1000 tons. It will be observed, that in the former Table the depth of the different vessels is very irregularly increased in proportion to their breadths. The average depth of the sloops and smacks is about 5-9th of their breadth; schooners and brigs from 7-12ths to 3-4ths; and large brigs and ships from 3-4ths to 2-3ds.

A Table of the Length, Breadth, and Depth of Boats, Sloops, and Smacks.

Class.	Length.	Breadth.		Depth.		Tonnage.	Class.	Length.	Breadth.		Depth.		Tonnage.
	Feet.	Feet.	In.	Ft.	In.			Feet.	Feet.	In.	Feet.	In.	
Boats.	8	3	6	2	0	...	Sloops.	38	13	8½	7	2	29.56.11
	10	4	0	2	0	0.60.10		40	14	3¼	7	9	33.91. 1
	12	4	9	2	2	1. 2. 0		42	14	10½	8	1	38.69. 5
	14	5	6	2	6	1.67.10		44	15	5¼	8	5	43.87. 6
	16	6	3	2	10	2.51. 3		46	16	0½	8	9	49.53. 3
	18	7	0	3	2	3.56. 1		48	16	7½	9	1	55.62. 0
	20	7	8½	3	6	4.76. 7		50	17	2½	9	5	62.21. 8
	22	8	5	3	10	6.36. 4		52	17	9½	9	9	69.27.10
	24	9	1½	4	2	8.13. 3		54	18	4½	10	1	76.82. 4
	26	9	10	4	6	10.31. 9		56	18	11	10	5	84.92. 9
	28	10	6½	4	10	12.68. 2		58	19	5½	10	9	92.89. 1
	30	11	2½	5	2	15.42. 8	Smacks.	60	20	0	11	1	102.12. 0
	32	11	10½	5	6	18.51. 4		62	20	6½	11	5	111. 9. 2
	34	12	6	5	10	22. 2. 3		64	21	1	11	8	121.38. 8
	36	13	1½	6	6	25.59. 3		66	21	7½	11	11	131.42. 4

Table of the Length, Breadth, and Depth of Boats, Sloops, and Smacks—(continued.)

Class.	Length.	Breadth.		Depth.		Tonnage.	Class.	Length.	Breadth.		Depth.		Tonnage.
	Feet.	Feet.	In.	Feet.	In.			Feet.	Feet.	In.	Feet.	In.	
Smacks.	68	22	2	12	2	142.90. 8	Smacks.	90	28	2	15	5	308.45. 4
	70	22	8	12	5	154.12. 6		92	28	9	15	9	328.60. 9
	72	23	2½	12	8	165.80.11		94	29	4	16	1	349.62.11
	74	23	8½	12	11	178.15. 3		96	29	11	16	5	371.53. 7
	76	24	2½	13	2	191. 4.10		98	30	6	16	9	394.34. 5
	78	24	8½	13	5	204.50.10		100	31	1	17	1	418. 7. 1
	80	25	3	13	9	219.86.11		102	31	8	17	5	442.67. 3
	82	25	10	14	1	236. 5.10		104	32	3	17	9	468.28. 7
	84	26	5	14	5	252.90.10		106	32	10	18	1	494.80.10
	86	27	0	14	9	270.62. 1		108	33	5	18	5	522.37. 8
	88	27	7	15	1	289.15. 0		110	34	0	18	9	550.88. 9

A Table of the Length, Breadth, and Depth of Schooners, Brigs, and Ships.

Length.	Breadth.		Depth.		Tonnage.	Length.	Breadth.		Depth.		Tonnage.	Length.	Breadth.		Depth.		Tonnage.
Feet.	Feet.	In.	Feet.	In.		Feet.	Feet.	In.	Feet.	In.		Feet.	Feet.	In.	Feet.	In.	
50	16	5	10	1½	57.54	86	25	1	16	10½	237.41	122	31	11½	22	3	558.58
52	16	11	10	6	63.66	88	25	6	17	3	251.42	124	32	4½	22	6	583.15
54	17	5	10	10½	70.25	90	25	11	17	7	265.93	126	32	9	22	9	606.69
56	17	11	11	3½	77.24	92	26	4	17	11	281.6	128	33	1½	23	0	631.14
58	18	5	11	8	84.66	94	26	9	18	3	296.65	130	33	6½	23	3	657.49
60	18	11	12	0	92.56	96	27	2	18	7	312.82	132	33	10½	23	6	681.60
62	19	5	12	4	100.91	98	27	6½	18	11	328.69	134	34	3½	23	9	709.43
64	19	11	12	9	109.77	100	27	11	19	3	345.10	136	34	8½	24	0	738.3
66	20	5	13	2	119.16	102	28	3½	19	7½	362.0	138	35	1	24	3½	765.64
68	20	11	13	6	129.3	104	28	8½	19	10½	380.38	140	35	5½	24	7½	793.87
70	21	5	13	11	139.40	106	29	1	20	1½	398.37	142	35	10½	24	10½	824.73
72	21	11	14	3½	150.34	108	29	5½	20	5	416.82	144	36	3½	25	2	856.29
74	22	5	14	8½	161.79	110	29	10	20	8	436.1	146	36	8½	25	5	888.59
76	22	10½	15	1	173.31	112	30	2½	20	11½	455.62	148	37	1½	25	8	921.70
78	23	4	15	5	185.32	114	30	6½	21	2	474.66	150	37	6½	25	11	954.82
80	23	9½	15	9½	197.83	116	30	11	21	5	495.43	152	38	0	26	2	992.35
82	24	3	16	1½	210.92	118	31	3½	21	8	510.11	154	38	6	26	5	1032.4
84	24	8	16	6	223.90	120	31	7½	21	11½	537.44	156	39	0	26	8	1072.74

The lengths given in these Tables are the length for tonnage, *i. e.* that of the keel, adding the fore-rake of the stem; the breadths are the extreme breadths taken above or below the main-wales; and the depths are the depth of the hold from the under side of the main-deck plank at midships to the ceiling-plank next the limber-strake. The young shipwright will require to attend to these proportions very carefully; and he should be extremely cautious in deviating from these dimensions. He should be particularly cautious how he proportions one vessel from another. If we wish to build a vessel of 400 tons in the same proportion as another of 250, it will not be sufficient to say, as one vessel of 250 is to its breadth, so will another of 400 be to its breadth; for the tonnage increases as the cubes of the dimensions. Therefore, if we cube any of the principal dimensions of the given ship, and say, as the given tonnage is to the cube

of the given dimension, so is the tonnage of the other vessel to the cube of the required dimension, the vessels will then be in the same proportion. However, we have shewn that vessels of different magnitudes are not made in the same proportions, and that they are diminished in breadth as they increase in size. When they are 150 feet in length, the breadth is then one fourth part of the length; and beyond this they are continued in the same proportion, and must not be farther diminished.

The length, breadth, and depth, as given in the above tables, may be considered in a fair proportion; nevertheless, they may be varied a little to suit any particular trade. Vessels for the timber trade are generally built to have a good length, and with little round on the side, which answers the stowage of the cargo; so that the vessel will be sufficiently stiff, and at the same time easy in her motions in a seaway, by the homogeneous nature of her loading bringing the centre of gravity to its proper height in the vessel.

Method of Admeasuring Ships for ascertaining the Tonnage.

" The length shall be taken in a straight line along the rabbet of the keel of the ship, from back of the main stern-post to a perpendicular line from the fore part of the main stem under the bowsprit.

" The breadth shall be taken from the outside of the outside plank in the broadest part of the ship, either above or below the main-wales, exclusive of all manner of doubling planks that may be wrought upon the ship." 13th Geo. III. cap. 74.

Method of Calculating the Tonnage of Ships.

" From the length, taken as above mentioned, subtract three fifths of the breadth, taken as above; the remainder is esteemed the just length of the keel to find the tonnage. Then multiply this length by the breadth, and that product by half the breadth, and divide by 94; the quotient is deemed the true contents of the tonnage." 13th Geo. III. cap. 74; 26th Geo. III. cap. 60.

The above rule cannot be supposed to give the true tonnage of every vessel, as they differ so widely in their constructions; and therefore some vessels will carry nearly double their register tonnage, while others that are sharp will not carry near so much as their register tonnage.

Many rules have been proposed for measuring ships, but only those which propose to gage the cavity of the vessel by exact measurement can be correct and applicable to all kinds of vessels. Rules may indeed be given that would approximate more nearly to the true tonnage; but as they are complex and of little use, I shall, instead, offer a few useful observations on the construction of tables for calculating the tonnage.

As it is sometimes required to know the length of a vessel of which we have only the breadth and tonnage given, it will be necessary to reverse the operation for computing the tonnage from the length and breadth. The rule will stand thus: Multiply the number of tons, feet and inches, by 94; divide the product by the half breadth, and the quotient by the whole breadth; and to this quotient add 3-5ths of the breadth in feet and inches; the sum is the length sought.

The common tonnage-book begins with the breadth marked at the top of the page, and expresses in proper columns the number of tons and parts, according to a number of different lengths, varying by one inch, and may be taken to half an inch of the length. The breadths increase also regularly by the addition of an inch, every page containing the tonnage of a number of vessels of different lengths, and all of the same breadth. Therefore, if we have an easy method of computing the tonnage for a number of different lengths on the same breadth, we may, after those for one breadth is computed, proceed with another, and thus carry the table any length we may think proper.

Rule.—First find the tons feet and inches made by one foot of length, which divided by 12, the number of inches in a foot, will give the contents for one inch; then set down regularly the contents that every inch makes from one to twelve, likewise the number of tons feet and inches made by one foot of length; then take any convenient length in feet more than 3-5ths of the breadth, subtract 3-5ths of the breadth from the length, multiply the remainder by the breadth and half breadth, and divide by 94 as before directed; you will then have the calculated tonnage for that particular length, which, together with the table of tonnages before calculated for every inch up to the foot, will be the data from which all other lengths at that breadth are to be derived. The preceding part of the rule may be shortly exemplified thus: For a ship of 21 feet in breadth,—One foot of length = 2 tons 32 feet (or 94th parts) and 6 inches; then 2 tons 32 feet 6 inches $\div$ 12 = the content for one inch, which is 18 feet $4\frac{6}{12}$ of an inch; and 18 feet $4\frac{6}{12}$ inches $\times$ 2 = 36 feet 9 inches = the content of 2 inches; also 18 feet $4\frac{6}{12}$ inches $\times$ 6 = 1 ton 16 feet 3 inches = the content of 6 inches; and in the same manner with all the other inches.

Next, let us suppose the length to be 40 feet, and breadth 21 feet, which calculated by the common rule gives a tonnage of 64, 26 feet $3\frac{9}{12}$ inches.

Now all that is required to be done to find the tonnage for any other length of feet and inches above or below this calculated length, is merely to add or subtract as many times the product of the one foot or inch just found, as is required to make the given length.

Example.—A ship 40 feet in length and 21 feet in breadth = 64 tons 26 feet $3\frac{9}{12}$ inches; then let it be required to find the tonnage for 41 feet 3 inches of length, and the same breadth:—

	Tons.	Feet.	Inch.	Pts.
Thus the tonnage for 40 feet of length . . .	= 64	26	3	9
Ditto ditto for 1 foot of length	= 2	32	6	0
Ditto ditto for 3 inches of length . . .	= 0	55	1	6
And lastly, the tonnage of 41 feet 3 inches at 21 feet of breadth	= 67	19	11	3

Again, suppose the tonnage is required for 52 feet of length, which is 12 more than 40 feet:—

	Tons.	Feet.	Inch.	Pts.
The tonnage for 40 feet of length is .	= 64	26	3	9
And of 1 foot = 2 : 23 : 6, which repeated 12 times	= 28	14	0	0
Which gives the tonnage for 52 feet	= 92	40	3	9

In calculating for one foot, it must be supposed one foot more than 3-5ths of the

breadth; for, if we suppose a vessel 12 feet long and 20 feet in breadth, then, by taking 3-5ths of the breadth from the length, there would be nothing left; so that when calculating the tonnage for one foot of length, it is properly for the 13th foot. Therefore, on this account, the tonnage cannot be added or multiplied into any number of feet or inches, to give the true tonnage according to a given length, before the 3-5ths of the breadth has been taken from the length. For, let the breadth be 20 feet, and length 24 feet, one foot of this length produces 2 tons 12 feet, and 24 times that would be 51 tons 6 feet; whereas the proper tonnage by the calculation, after deducting 3-5ths of the breadth, is only 25 tons 50 feet; for at the length 24 and breadth 20, there is only one-half of the contents measured by the rule established by law; and in this case, when the length is only one and 1-5th times the breadth (as 24 to 20), there is a loss of one-half of the real tonnage; when the length is two and 2-5th times the breadth, the loss is 1-4th; and if 3 and 3-5th times the breadth, the loss is only 1-6th; and so on, decreasing in proportion as the length increases, and which is exhibited in the following table:—

Table for shewing the Deficiency of real Tonnage, when calculated by the established rule for measuring Ships, i.e. *taking 3-5ths of the breadth from the length, and supposing the breadth to be 20 feet, and the length to be continually increased by 1-5th of the breadth, beginning at a length which is exactly 3-5ths of the breadth.*

Breadth.	Length and Proportion of Breadth.	Proportion of the true Tonnage lost by deducting 3-5ths of the Breadth from the Length.	Breadth.	Length and Proportion of Breadth.	Proportion of the true Tonnage lost by deducting 3-5ths of the Breadth from the Length.
	$12 = \frac{3}{5}$ of 20	Minus whole, no Ton^ge.		$80 = 4$ times 20	Minus $\frac{3}{20}$ of true Ton^ge.
	$16 = \frac{4}{5}$ of ,,	$\frac{3}{4}$ of the true do.		$84 = 4$ & $\frac{1}{5}$,,	$\frac{1}{7}$ ... ...
	20	$\frac{3}{5}$		$88 = 4$ & $\frac{2}{5}$,,	$\frac{3}{22}$ ... ...
	$24 = 1$ & $\frac{1}{5}$,,	$\frac{1}{2}$		$92 = 4$ & $\frac{3}{5}$,,	$\frac{3}{23}$ ... ...
	$28 = 1$ & $\frac{2}{5}$,,	$\frac{3}{7}$		$96 = 4$ & $\frac{4}{5}$,,	$\frac{1}{8}$ ... ...
	$32 = 1$ & $\frac{3}{5}$,,	$\frac{3}{8}$		$100 = 5$ times ,,	$\frac{3}{25}$ ... ...
	$36 = 1$ & $\frac{4}{5}$,,	$\frac{1}{3}$		$104 = 5$ & $\frac{1}{5}$,,	$\frac{3}{26}$ ... ...
	$40 = 2$,,	$\frac{3}{10}$		$108 = 5$ & $\frac{2}{5}$,,	$\frac{1}{9}$ ... ...
20	$44 = 2$ & $\frac{1}{5}$,,	$\frac{3}{11}$	20	$112 = 5$ & $\frac{3}{5}$,,	$\frac{3}{28}$ ... ...
	$48 = 2$ & $\frac{2}{5}$,,	$\frac{1}{4}$		$116 = 5$ & $\frac{4}{5}$,,	$\frac{3}{29}$ ... ...
	$52 = 2$ & $\frac{3}{5}$,,	$\frac{3}{13}$		$120 = 6$ times ,,	$\frac{1}{10}$ ... ...
	$56 = 2$ & $\frac{4}{5}$,,	$\frac{3}{14}$		$124 = 6$ & $\frac{1}{5}$,,	$\frac{3}{31}$ ... ...
	$60 = 3$,,	$\frac{1}{5}$		$128 = 6$ & $\frac{2}{5}$,,	$\frac{3}{32}$ ... ...
	$64 = 3$ & $\frac{1}{5}$,,	$\frac{3}{16}$		$132 = 6$ & $\frac{3}{5}$,,	$\frac{1}{11}$ ... ...
	$68 = 3$ & $\frac{2}{5}$,,	$\frac{3}{17}$		$136 = 6$ & $\frac{4}{5}$,,	$\frac{3}{34}$ ... ...
	$72 = 3$ & $\frac{3}{5}$,,	$\frac{1}{6}$		$140 = 7$ times ,,	$\frac{3}{35}$ ... ...
	$76 = 3$ & $\frac{4}{5}$,,	$\frac{3}{19}$		$144 = 7$ & $\frac{1}{5}$,,	$\frac{1}{12}$ ... ...

Having determined the general dimensions of length, breadth, and depth, and shewn the method of measuring and calculating the tonnage, we shall now proceed, in the first place, to explain the various pieces of timber which compose the principal parts of the ship,—and, in the second place, give rules for finding the dimensions, particularly of those parts and pieces of timber which require to be drawn to the proper size on the various plans, sections, &c.

On the Timbers which compose the Principal Parts of a Ship, the Method of Fastening, &c.

As it would be an endless task to point out to the reader the mechanical ingenuity which is displayed in the joinings and fastenings of the different pieces of timber of which the vessel consists, I shall merely present him with a view of them in their respective situations. The particular methods of working, fitting, and fastening the various frames and timbers together, will be found fully described in the practical part of this work.

The principal piece of timber, and which is the first prepared, is the keel, which answers the purpose of the back-bone, across which the frames of timber are placed, which answer the purpose of the ribs, which are again covered with planks, answering the purpose of the skin. Before entering into details, the reader will be pleased to refer to *Plate* X., on which we have endeavoured to represent the principal timbers of construction. *Figs*. 1 and 1′ shew the bow and stern ends of a ship of about 350 tons. To save room on the plate, the vessel is not represented at full length, as the parts in midships, as seen in the longitudinal section, are less important than the fastenings of the two ends. The principal piece of timber, *i. e.* the keel, is marked with the letters A A A A, and extends from the stem to the after-side of the stern-post. As it is impossible to obtain timber large enough to make the keel of one piece for vessels of any considerable size, it must therefore be joined together in two or three, as the case may require, and the manner of joining it, is called *scarphing*. The ends to be joined together being thinned away, are made to overlap one another, and sometimes the scarph is made plain, as represented by *Fig*. 4, but oftener with a tenon and mortise, as shewn by *Fig*. 5, the tenon being raised on the thin part of the scarphs, and the mortise towards the thick part. This method of scarphing is preferable to a plain scarph, and is called a hook-scarph; it stands edgeways, and is bolted with eight bolts. The piece of timber next to the keel is the stem, and is that piece which is joined on the fore end of the keel, marked B B′, by means of a scarph, represented by *Figs*. 6, 7, or 8. The stem is commonly in two pieces, as it is difficult to procure timber large enough, and of the proper shape, to reach from the keel up to the under side of the bowsprit; the scarph of the stem is also a hook-scarph. The piece of timber marked C C′ is called the apron, or stomach-piece, or fore-deadwood. In a ship of this size, it consists of three or four pieces, and is scarphed, as shewn in the plate, the scarphs very properly breaking joint, or making shifting over those of the stem. The apron is bolted down to the fore end of the keel, and to the stem. With respect to the three methods represented by *Figs*. 6, 7, and 8, the first is considered to be the best and most secure; the other two, being simpler, are more easily made. It has not been ascertained exactly whether *Fig*. 8, in which the fore end of the keel turns up into the curvature of the stem, is preferable to *Fig*. 7; the latter, however, is most generally adopted. The dotted lines represent the bolts for fastening the pieces together. The filling-piece (marked D) is called the cutwater or fore-foot, or gripe, and is put on chiefly to increase the dimensions of the lower part of

the stem. By means of a good gripe, the vessel holds her head better to windward when sailing. In general, the cutwater means the whole of the filling-on pieces of the stem, which form the projecting part on which the figure of the head is placed. The piece marked E is called the head-knee, F the lacing-piece, and G the block for the figure.

We shall now explain the stern-post, and the pieces by which it is secured. The main stern-post is the upright piece marked H H; it is inserted into the after-end of the keel by two tenons, and held down by two dovetailed plates, as represented by *Fig.* 9, or as by *Fig.* 10. On the inside of the main stern-post is fitted the piece marked I I, called the inner post; it is also inserted into the after-end of the keel by one or two tenons, and fastened on to the main post with a few dowals or coags, and afterwards by the bolts which secure the transoms and dead-woods to the post. The piece marked J J is the false stern-post, and is commonly used for large vessels; but if a piece of timber large enough for the main stern-post can be procured, a false stern-post is unnecessary. The large pieces marked K K K are called the dead-woods; they are fitted close to the keel and on each other, and have a few dowals for securing them more completely; their ends are let into the inner-post with tenons, or chacked in a bevelled manner, as represented in the plate. The dead-woods are for raising up the after-floors to suit the rising of the run of the vessel, and for properly securing the stern-post and the heels of the cant-timbers. The crooked piece L L, which fits on the dead-wood, and turns up against the inner-post, is called the heel-knee, as it secures the post to the dead-woods and keel, being bolted to both. A knee means any crooked piece of timber, as represented by *Fig.* 14, and is used for binding together any pieces of timber which meet transversely or at angles, as shewn by *Fig.* 15. The pieces marked M M M (*Figs.* 1 & 1') are the sections of the floor-timbers, and are the principal pieces of the frames; they are represented by the pieces M M M (*Figs.* 16 and 19), and their rising as they go forward is shewn by *Fig.* 20. *Fig.* 16 exhibits the midship frame, with the binding, beams, planks, &c. *Fig.* 26 represents the different timbers which compose the frame, supposing them to be expanded. *Fig.* 25 shews a part of the keel and of the midship frame, and the letters on *Figs.* 25 and 26 correspond to the same parts; M M the floor, N the first futtock, O the second futtock, P the third futtock, Q the fourth futtock or long top-timber, R the short top-timber. These timbers are sometimes fitted close together, but more frequently they are placed a little apart, and have a piece of wood between them, through which the bolt which fas tens them together passes, as shewn by *Fig.* 26. *Fig.* 16 is the midship frame; the various bindings will be obvious from an inspection. The pieces marked S S are the chocks, and serve to scarph the ends of the timbers together. Instead of using chocks in the manner described, the chock may be dovetailed, so as to make a more secure fastening; but if they are well fitted, it will answer every purpose. Some of the Navy people use a square butt and a coak or dowal in place of the chock, as they consider it superior to the common chock, and the philosophical reasoning employed in support of the opinion cannot be controverted. The general opinion of practical men is in favour of the common method of cross-chocking the butts of the timbers. I consider a method of scarphing them, where it can be obtained, as preferable to either.

The longitudinal pieces (*Figs.* 1 and 1′, *Plate* X.) marked T T, &c. called the kelsons, are fitted down to the top of the floors, and extend from the apron or stomach-piece to the heel-knee or after-deadwoods; they are fitted with flat scarphs, sometimes hooked and sometimes plain, and the upper piece should be run as straight as possible, which materially assists in preventing hogging. On the fore-end of the kelson, and up the inside of the apron, is fitted the piece marked U U, called the stemson, which, from its shape and purpose, might be called the stem-knee; it is bolted firmly through the stem, and by the bolts of the breast-hooks passing also through it. The breast-hooks are strong pieces of timber, which extend across the inside of the bow, and bind the two bows of the vessel properly together, as represented by *Fig.* 23, V V being the breast-hook bolted to every timber of the bow, which in general is considered sufficient, but may have two bolts in some of the timbers of the bows, if there is any necessity for its being very strong. The pieces marked V V (*Fig.* 1′) represent the sections of the breast-hooks in their respective situations. W W is a piece bolted on to the top of the kelson, into which a mortise is cut for receiving the foot of the masts; these pieces are therefore called the steps of the masts; *x x* the beams of the main and 'twixt-decks; Y the pawl-bitt for securing the windlass, and Z the mast and the bowsprit.

Fig. 2 exhibits a front view of the bow, the one side being merely in frame and the other planked; A is the fore-end of the keel, B the front of the stem. The piece of timber next the stem, marked N 1, is bolted firmly to it before it is put up, and is called the knight-head or bollard-timber; the pieces 2 and 3 are called the hawse-timbers, as the hawse-holes pass through them; the other pieces 4, 5, 6, &c. are merely called bow-top timbers, or bow-timbers. We have also endeavoured to represent the shiftings of the timbers on this figure; M the floor-timber, N the first futtock, O the second futtock, P the third futtock, &c. in the same manner as shewn by *Figs.* 25, 26, and 16. The principal distinctions of the plank are represented by *Figs.* 2 and 16. The plank next the keel, marked 1, is called the garboard-strake; from that to 2 is called the bottom-plank; from 2 to 3 is the bilge-plank—these are thicker than the other planks of the bottom. From 3 to 4 the bottom plank, from 4 to 5 the diminishing plank or strakes, from 5 to 6 the main-wales or bends; these are also considerably thicker than the bottom-plank, and are put round the vessel about the line of floatation, and at the place of the 'twixt-deck beams, to give a greater strength at that part, and afford better fastenings to the 'twixt-deck beams. From 6 to 7 is called the black-strakes, from 7 to 8 the top-sides plank, and from 8 to 9 the paint-strakes or sheers-plank, 10 the gunwale or plank-sheer, or covering board; from 10 to 11, the bulwarks. Of the planks on the inside of the timbers, called the ceiling-planks, clamps, stringers, &c. &c., the plank *a* is called the limber-board or limber-strake; it is canted up against the side of the kelson, to allow a run for the water, *b*; from *b* to *d* is the common ceiling-plank, from *d* to *e* the inside bilge-plank; *f*, thick-stuff on the first foothook-heads; from *s* to *g*, ceiling-planks; the piece *g* is called the shelf for the hold beams; the clamp is the thick plank against which the shelf-piece fits; the ends of the beams are rested on the shelf, and fastened down with a dowal and two bolts, as shewn in the plate. The upper-deck beams are fastened down to the shelf *i* in the

same manner; the strake *j* is called the water-way, as it is the side deck plank, and is formed with a gutter for running the water off the deck to the scuppers. The shelf-pieces and clamps are hook-scarphed, as shewn by *Fig.* 18, and bolted to every timber of the side. The beams are fastened to the ship's side with wood or iron knees, or both; the wooden knees rest with their side-arm on the shelf or clamp, and are bolted to every timber, as shewn by *Fig.* 17. The iron hanging knees may either be single or double, as represented by *Fig.* 16; when they are double, they fit on the under side of the upper-deck beams, down the side and along the top of the 'twixt-deck beams, in which case they are called steaple standards, and are an excellent binding to a vessel, if properly bolted, being preferable to wooden knees, as they occupy so little room in the vessel, and break the stowage little or nothing.

We must now return to the stern part, *Figs.* 1 and 3, to notice the transoms, &c. *Fig.* 3 is an after view of the stern-frame and stern-timbers; A is the after-end of the keel; H H the after-side of the stern-post. The large piece of timber which runs across the the inside of the stern-post, marked W T, is called the wing-transom, and is the principal of a number of transoms which run across in the same manner, marked 1, 2, 3, 4, 5, 6. *Fig.* 12 represents the wing-transom when viewed from the inside of the ship; and *Fig.* 13 may be taken to represent some of the other transoms, as No. 3 or 4. The wing-transom is fastened to the stern-post with two stout bolts, as represented in *Fig.* 12, and all the others by one bolt. The ends of the transoms are cut to the bevel, as represented by *Figs.* 12 and 13, and a piece of timber is fitted on their ends, marked M, *Fig.* 3, called the fashion-timbers, the shape of which is more distinctly seen by *Fig.* 11. On the top of the wing-transom stand the stern-timbers, marked D; also the quarter-timbers, marked E, *Fig.* 3. The quarter-timbers are secured to the wing-transom by the knees F; on the outside of the quarter-timbers are fitted the pieces marked G, called the quarter-pieces, for forming the quarter-gallery; on the inside of the seat of the transoms is fitted the rider H, the lower end of which fits also on the upper side of the kelson, and is bolted through all.

Figs. 21 and 22 represent two of the most approved methods of building the rising floor-timbers, forward and aft. *Fig.* 21 is, by placing two timbers directly opposite, chocking and bolting their heels into the dead-wood, then laying a stout piece across the top of the kelson, bolting it firmly to each of the timbers, and lastly, securing it down to the kelsons by a bolt, as shewn in the figure. The other method is by fittings, and scarphing a piece to the short arm of any knee, so as to make it answer for a quick rising floor.

Having described some of the principal pieces of construction, we may observe, with respect to the other figures on the plate, that *Fig.* 27 is a diagram in illustration of the principles of forming a proper sheer for the upper-works of a vessel; *Figs.* 28 and 29 is a method of binding the ends of the beams to the side, &c.; *Figs.* 30 and 31 a method of scarphing beams; *Figs.* 32, 33, and 34, a plan and section of a new mode of laying decks; *Fig.* 35 a method of filling the floors, and having 6 or 8 inches of solid keel within the garboard-strake. These figures will be fully explained in the practical part of this work, &c.

Rules for the Dimensions and Proportions.

1*st*, *Of the Keel.*—The keel should be sided one half inch for every foot of the ship's extreme breadth. And the hanging under the rabbet is equal to the siding; it should therefore be in depth equal to its siding dimension, adding the breadth of the rabbet for the garboard-strake.

2. *The Stem.*—The stem should be sided at the lower end 11-12ths of the siding of the keel in midships, and the same as the keel in midships at the top. It should be moulded to 14 or 15-12ths of its siding dimension.

3. *The Stern-post.*—The stern-post should be sided at the lower end 11-12ths of the keel in midships, and at the upper end the same as the keel in midships. It should be moulded at the lower end about double of its siding, and at the upper end equal to its siding at the same.

4. *The Dead-woods.*—The dead-woods are commonly sided the same as the keel at their lower edges, but the upper part of the apron on the stem, and fore-edge of the inner post, about 1-5th or 1-6th larger. The dead-woods are moulded according to the size of the vessel.

5. *Scarphs of the Keel.*—The scarphs of the keel should be in length twice the breadth and twice the depth of the keel, and be fastened with eight bolts, varying in diameter according to the size of the ship.

6. *Scarphs of the Stem.*—The scarph of the stem should be in length about three times its moulding dimension, and fastened with six bolts.

7. *Floor-Timbers.*—The floor-timbers, at the keel, for coasting vessels, should be moulded one half inch for every foot of the ship's extreme breadth, and sided about 10 or 11-12ths of their moulding dimension. Large vessels rather a less proportion.

8. *The Kelson.*—The kelson should be sided as the keel, and should be in depth one inch for every foot of the ship's breadth, and the scarphs should not be shorter than five times the depth. They should be secured with eight bolts.

9. *The Transoms.*—The transoms should be sided, first, the wing-transom the same as the midship floors; all the others about 7-8ths of the wing-transom. They should be moulded the same as the floors.

10. *The Breast-hooks* should be sided and moulded as the midship floor, and their length be 5-8ths of the ship's extreme breadth.

11. *The Deck-beams for a Smack.*—The beams for a smack, or any other large vessel, which is chiefly bound by the beams of the upper deck, require more strength in proportion than for those vessels which have two properly bound decks. Smacks, therefore, should have three or four of their midship beams sided one half inch for every foot of their length, and moulded in the middle to the same. Their ends, when the vessel is to be bound with iron hanging knees, may be moulded 2-3ds of their depth in the middle; but when the vessel is to be bound with sunk water-ways and stringers only, the beam ends should not be thinner in the middle than 5-7ths of their mouldings.

12. *The Beams for a Brig.*—For the siding and moulding in the middle, take 3-7ths

of the length of the beams in feet, and call that inches: and make the moulding at their ends 5-8ths of the middle; and the same proportion will answer for a ship's main and 'twixt-deck beams.

13. *For the round of the Beams.*—For the round of the beams of the main-deck: to the length of the longest beam add the thickness of the timbers on each side; then take 3-8ths of an inch for every foot of that length for the round-up; and the round of the lower or 'twixt-deck beams is the same as that of the under side of the main-deck beams.

14. *The Pawl-bitt.*—This piece of timber stands in a vertical position at the fore side of the windlass, and to it are attached the pawls which prevent the windlass from turning round in the reverse direction. As there are very great strains occasionally on the pawl-bitt, it ought to be a good, sound, strong piece of timber, as the safety of the ship and lives of the crew frequently depend upon the security of the windlass. The windlass, therefore, with its connecting parts, should be of the best materials and workmanship. The pawl-bitt should not only have sufficient strength to withstand the heavy jerking strains to which it is exposed without breaking, but also to be so strong as will prevent it from springing back at the top, by which the upper pawls are thrown off the centre, or from being drawn back from the ratchets in the pawl-ring, leave the whole strain upon the lower pawls, which are sometimes broke in this manner, and the windlass is then useless.

As the strain upon the cable of a vessel when at anchor is in proportion to her magnitude, the strength of the pawl-bit, as well as the cable, should be estimated by the length, breadth, and depth of the ship, but particularly by the breadth. In order to find the size of the pawl-bitt, first deduct the thickness of the keel from the ship's extreme breadth as taken for register, and add one half of the same to itself. Call the feet inches, and inches parts, and one-third of that sum will be the siding dimension of the pawl-bitt; also 3-8ths of the same will be the dimension the fore-and-aft way; or by taking half the reduced breadth for the siding way, and adding 1-8th of that to itself, will give the depth the fore-and-aft way. Thus, suppose the ship's breadth 27 feet, and keel 1 foot; required, the size of the pawl-bitt?—$27 - 1 = 26$, and $26 + 13 = 39$, and $39 \div 3 = 13$ inches for the siding dimension. Again, $39 \times \frac{3}{8} = 14\frac{5}{8}$ inches for the fore-and-aft dimension.*

15. *The Chocks for fixing the Windlass-bitts* should be as strong as the beams at the place to which they are fixed.

16. *The Length of the Windlass between the bitts* is commonly one-half of the breadth of the ship's main deck amidships.

17. *The Diameter of the Windlass.*—Take the extreme breadth of the vessel, and call the feet inches, and the inches parts, and 2-3ds of it will be the diameter of the windlass

* It may appear at first that some easier rule than the above might be given; but we must observe, that it was found impossible to devise any other that would give the dimensions of the pawl-bitt in so fair, correct, and just a proportion, for all sizes of vessels from 40 to 50, up to 400 or 500 tons.

in inches and parts; or, what is nearly the same, make the diameter of the windlass 2 inches for every 3 feet of the ship's extreme breadth.

18. *Size of the Windlass Spindles.*—These are commonly 1-8th part of an inch for every foot of the ship's extreme breadth. For such vessels as are deep in the hold, it will be necessary to proportion them thus:—To one and a half of the ship's extreme breadth, add one-half of what the depth of the hold exceeds the half of the ship's breadth; by dividing the sum by 12, the quotient will be the diameter of the windlass spindles in the round. Thus suppose a ship's extreme breadth is 27 feet, and depth of hold 20 feet; required, the diameter of the windlass spindles in the round?—By the first rule, 1-8th of 27 is $3\frac{3}{8}$ inches for the diameter; by the second rule, $27 + \frac{1}{2} = 40$ ft. 6 in., and $20 - 13 \cdot 6 = 6 \cdot 6$; and $\frac{1}{2}\ 6 \cdot 6 = 3 \cdot 3$; then $40 \cdot 6 + 3 \cdot 3 = 43 \cdot 9$, and $43 \cdot 9 \div 12 = 3\frac{5}{8}$ inches for the diameter. So that the diameter by the first rule is $3\frac{3}{8}$ inches, and by the second, $3\frac{5}{8}$ inches, which is a little stronger for a deep vessel.

19. *The Windlass Bitts.*—These may be proportioned either by the breadth of the ship, or the diameter of the spindles of the windlass: if by the breadth of the ship, make the thickness of the bitts 5-8ths of an inch for every three feet of the ship's extreme breadth; if by the diameter of the spindles, double the diameter of the spindle, multiply it by five, and divide the sum by six, and the quotient is the thickness of the bitts. If we make the thickness of the windlass-bitts one-third of the diameter of the windlass, they will be in a good proportion.

20. *The Cat-Heads.*—These should be sided equal to 1-3d of the ship's extreme breadth, taking inches for feet, and may be 1-7th or 1-6th more in depth.

21. *A Smack's Fore-sheet Horse,* if made of wood, should be one inch thick for every three feet of its length, and clear of knots on its upper edge.

22. *The Capstan.*—The following proportions will give the diameter of the capstan spindle, the size of the barrel, the breadth of the top, and the size of the whelps:—

1*st*, *To find the diameter of the Spindle.*—Add the depth of the ship's hold to her extreme breadth, and dividing the sum by 12, the product is the diameter of the spindle in inches. Thus suppose the ship's breadth 27 feet, and depth of hold 18 feet,—$27 + 18 = 45$, and $45 \div 12 = 3\frac{3}{4}$ inches for the diameter of the spindle.

2*d*, *To find the diameter of the Barrel.*—Take 3-7ths of the ship's extreme breadth in feet and inches, and the product is the diameter of the barrel in inches and parts. Thus 3-7ths of $27 = 11\frac{4}{7}$ inches, the diameter of the barrel.

3*d*, *The diameter of the Drum-head* is 12-10ths of the ship's breadth, inches for feet. Thus 12-10ths of $27 = 32\frac{5}{8}$ inches, for the diameter of the drum-head.

4*th*, *For the size of the Whelps.*—These are commonly made one half or 5-9ths of the diameter of the barrel.

23. *The Rudder.*—I shall offer a few observations regarding the dimensions of the rudder. The good or bad performance of the rudder depends upon various particulars, the chief of which are the construction of the bottom of the vessel, the situation of the masts and sails, and the dimensions of the rudder itself. The proper dimensions of the rudder is, perhaps, the most important of these; for a vessel may have a well-con-

structed bottom, her masts and sails properly placed, and yet, if the rudder be not duly proportioned to the vessel, she will not steer well. The following dimensions are considered to be the best for the rudder.

1st Dimension.—Make the rudder one and a half inches broad at the lower end, for every foot of the ship's extreme breadth, or between 1-7th and 1-8th of the ship's extreme breadth, exclusive of the breadth of the bearding of the fore-edge, and let the breadth at the load-water line or lower hance be about 2-3ds or 5-8ths of the breadth at the keel or lower end. This dimension is found to answer very well for regularly-built merchant ships, even allowing them to be rather sharp; this breadth, therefore, must not be much diminished, for although a vessel is thin and sharp abaft, whereby the water will reach the rudder more freely, yet it is certain that the thinner the heel and after-run of the ship are, the greater will be the effort of the rudder required to push the stern of the vessel round; and for this reason, sharp vessels require nearly as broad a rudder as those which are only sufficiently sharp to allow the water a free passage to the rudder.

The above dimensions for the rudder, although the most suitable for vessels regularly formed in the bottom, and whose dimensions of length and breadth are also in a fair proportion, would be found rather small for vessels of a long construction, such as steamboats or the like, because the additional length not only increases the weight, but also presents a greater surface of the bottom and runs to the horizontal pressure of the fluid, while the vessel is coming round. In such a case, the length as well as the breadth of the vessel should be taken into consideration in finding the just proportion of the rudder; and hence this second dimension for the breadth of the rudder:—To the length of the ship at the load-water line (or to the length per register, which is nearly the same in most vessels), add one and a half the extreme breadth of the ship in feet and inches, and of the sum take 1-3d for the breadth of the rudder in inches and parts. Thus suppose a ship's length is 94 feet; ditto extreme breadth $= 27$ feet. Then $94 + 27 + 13$ ft. 6 in. $=$ 134 ft. 6 in., and 1-3d of 134 ft. 6 in. $= 44\frac{5}{6}$ inches for the breadth of the rudder.

When a ship will not steer with this proportion of rudder, she is either too full abaft, or there is something faulty in the placing of the masts. When this is the case, a few inches of breadth may be added to the rudder, such as 1-10th of the above proportion; if this be still found insufficient, enlarge the breadth of the stern-post, by means of a false post, or piece put to the after-side of the stern-post, rather than increase the breadth of the rudder to any greater extent.

In order to proportion the breadth of the rudder more exactly to the ship, according to her particular construction, it will be proper to divide shipping into three classes generally, and then make the proportions suitable.

Let the first class consist of those vessels that have pretty sharp bottoms, such as are for fast sailing; let the second class be those that are regularly built for trading merchant ships; and the third, of such vessels as are very full, being long narrow burdensome vessels. For the breadth of the rudder for a ship of the first class, take 1-8th part of her extreme breadth; for the rudder of a vessel of the second class, make its breadth at the lower end 2-15ths of the ship's extreme breadth; and for the breadth of the rudder of the third class, take 1-7th of the extreme breadth of the vessel.

24. *The Rudder-head.*—The rudder-head or rudder-stock, is that part of the rudder which passes up through the counter to the deck, and into which the tiller is fixed. The rudder-stock should be a piece of timber of the best quality, because the whole strain of the rudder in steering the vessel is constantly acting upon this piece, as the tiller is acting in direct opposition thereto; if this piece of timber be weak or shacky, it will soon become loose and twist, and yielding to the force of torsion, prevent the full action of the rudder.

The dimension of the rudder-stock, like that of the rudder itself, should be in proportion to the bulk of the vessel; therefore see the method of finding the breadth of the rudder by dimension 2d, but in place of taking 1-3d of the sum, take 1-10th for the square of the rudder-head in inches and parts, and, if the size of the timber will allow, the rudder-head may have its breadth the fore-and-aft way made 1-10th more than the cross way.

25. *The Rudder-bands* are the hinges on which the rudder turns in steering the vessel. They are sometimes made of iron, but oftener of a composition of copper and tin, as the latter is found to be more durable, from its not corroding by the action of the salt water; the bands below water being composition, those above may be made of good wrought iron. Each of them consists of a pair of legs or braces joined together, the width between the legs being equal to the thickness of the stern-post or rudder. Those which fit on the stern-post have a round hole in their after-end, and are called the braces; those which fit on the rudder have a strong pin or pivot on their fore-end, standing commonly at right angles to the edge of the legs or braces, which pin or pivot passes down through the hole in the braces on the stern-post, and connecting the rudder to the same, constitutes the hinge. The size of the legs or bands is made proportional to the diameter of the pivots or pintles, which is their most common name. In proportioning the rudder-bands, therefore, to the size of the vessel, we must first find the diameter of the pintles, and from them the size of the legs or bands.

These dimensions are seldom mentioned in contracts; it is only stated whether they are to be made of copper or iron, while their number and dimensions are left undetermined. This circumstance often causes disputes between parties, as to what their exact size should be.

Among the different works on shipbuilding which I have examined, no proper rules have ever been given for calculating the dimensions of the rudder-bands, in proportion to the different size of vessels; I have therefore been induced to examine the subject, and mark out some general rule consistent with practice. In the first place, we must consider that the whole strain of steering will ultimately fall upon the rudder, and it will be greater or less according to the following circumstances, *i. e.* the magnitude of the vessel, the good or bad form of bottom for steering, the position of the masts, the depth to which she is immersed, and the direction in which she is steered with respect to the run of the waves and strength of the wind. But allowing all these, there is one general proportion for the size of the rudder for all common sea-going vessels; the size of the bands, however, by which it is connected to the stern-post, is still undetermined.

In order to obtain a rule for determining their requisite strength for all sizes of vessels, I was induced to make a trial of several methods, to produce a regular proportion for the number of bands, the size of the straps, and diameter of the pintles; for which purpose, I ascertained the number of bands, their size respectively, and the diameter of the pintles, on a great many vessels of all classes, and found what proportion their diameters bore to the tonnage of each vessel, and to the squares of their diameters. Ascertaining, however, that no direct rule could be deduced from the tonnage alone, nor from the length, breadth, or depth, or these combined, a trial of the following method was made, and found to produce such a proportion as answers every dimension of vessel from 40 to 1000 tons.

Rule.—To 2-3ds of the number of the regular tonnage of the ship, add her length on the load-water line and her extreme breadth *per* register; divide the same by 13, and the quotient is the squares of the diameters of all the pintles of the bands below the counter, in inches and parts; this being again divided by the number of bands, gives the square of the diameter of each pintle, the square root of which is the dimension sought.

Example.—Suppose we have a vessel whose length on the load-water line is 94 feet 6 inches, and extreme breadth 27 feet, making the register tonnage 303; then let it be required to find the diameter of the pintles of the rudder-bands?—$303 \times \frac{2}{3} = 202 + 94.5 + 27 = 323$, and $323 \div 13 = 24.88$ = the squares of all the pintles below the counter, and $24.88 \div 4 = 6.22$, and $\sqrt{6.22} = 2\frac{1}{2}$ inches for the diameter of the pintles, as required, in a very just proportion to the size of the vessel; but in this example we may substitute 25 for 24.88, and as the lower bands are in general stronger than those towards the top of the rudder—

Take	6.89	for the square of the pintle of the lower band,			
And	6.25	for the	do.	do.	of the second band,
	6.25	for the	do.	do.	of the third band,
	5.64	for the	do.	do.	of the band at the counter;
	25.03				

So that these when added make 25; and taking their square roots respectively, we shall have—

$\sqrt{6.89} = 2\frac{5}{8}$	inch for the diameter of the pintle of the lower band,			
$\sqrt{6.25} = 2\frac{1}{2}$	do.	do.	do.	of the second band,
$\sqrt{6.25} = 2\frac{1}{2}$	do.	do.	do.	of the third band; and
$\sqrt{5.64} = 2\frac{3}{8}$	do.	do.	do.	of the upper band.

The diameters of the pintles being found, the breadth of the bands are made equal to one and a fourth times the diameter of the pintle, and the thickness at the shoulder equal to half the diameter of the pintle. According to these rules, the following Table has been calculated of the number and size of the rudder-bands, and of the medium sizes of the different classes of vessels:—

Table of the number and size of the Rudder-bands, &c.

Class of Vessels.	Tonnage.	Ships' Length.		Ships' Breadth.		Sum of the Squares of the Diameter of all the Pintles.	No. of Bands.	Diameter of the Lower Pintle.	Diameter of the Pintle of the Second Band.	Diameter of the Pintle of the Third Band.	Diameter of the Pintle of the Fourth Band.	Diameter of the Pintle of the Fifth Band.	Diameter of the Pintle of the Sixth Band.	Diameter of the Pintle of the Seventh Band.	Mean Diameter of the Pintles.	Length of the Lower Band.		Mean Breadth of the Bands at the Shoulders.	Mean Thickness of the Bands at the Shoulders.
	Tons.	Feet.	In.	Feet.	In.			Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Ft.	In.	Inches.	Inches.
Sloops.	43.86	44	0	15	5	6.77	3	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{3}{8}$	...	...	...	...	$1\frac{1}{2}$	1	10	$1\frac{7}{8}$	$0\frac{12}{16}$
	61.0	50	0	17	0	8.28	3	$1\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{1}{16}$	...	...	...	...	$1\frac{11}{16}$	2	0	$2\frac{1}{8}$	$0\frac{13}{16}$
	102.0	60	0	20	0	11.33	3	$2\frac{1}{8}$	$1\frac{7}{8}$	$1\frac{3}{4}$	...	...	...	...	$1\frac{15}{16}$	2	3	$2\frac{7}{16}$	$0\frac{15}{16}$
Scho^{sr}.	151.0	72	0	22	0	14.97	3	$2\frac{3}{8}$	$2\frac{3}{16}$	$2\frac{1}{8}$	...	...	...	...	$2\frac{1}{4}$	2	6	$2\frac{13}{16}$	$1\frac{1}{8}$
Smack.	180.0	74	3	23	9	16.77	3	$2\frac{1}{2}$	$2\frac{5}{16}$	$2\frac{1}{4}$	...	...	...	...	$2\frac{3}{8}$	2	9	3	$1\frac{3}{16}$
Brigs.	205.0	83	6	23	7	18.76	3	$2\frac{5}{8}$	$2\frac{1}{2}$	$2\frac{3}{8}$	...	...	...	...	$2\frac{1}{2}$	2	9	$3\frac{1}{16}$	$1\frac{1}{4}$
	251.0	88	0	25	6	21.6	4	$2\frac{3}{8}$	$2\frac{3}{8}$	$2\frac{1}{4}$	$2\frac{1}{4}$	...	...	...	$2\frac{5}{16}$	2	11	$3\frac{1}{8}$	$1\frac{3}{16}$
	303.0	94	6	27	0	24.88	4	$2\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{3}{8}$	$2\frac{3}{8}$	...	...	...	$2\frac{1}{2}$	3	1	$3\frac{1}{16}$	$1\frac{1}{4}$
Ships.	347.0	102	6	27	7	27.81	4	$2\frac{3}{4}$	$2\frac{11}{16}$	$2\frac{5}{8}$	$2\frac{1}{2}$	...	...	...	$2\frac{5}{8}$	3	3	$3\frac{4}{16}$	$1\frac{4}{16}$
	400.0	108	0	28	9	31.04	4	$2\frac{7}{8}$	$2\frac{7}{8}$	$2\frac{3}{4}$	$2\frac{5}{8}$	...	...	...	$2\frac{13}{16}$	3	5	$3\frac{5}{16}$	$1\frac{6}{16}$
	455.0	112	0	30	0	34.25	5	$2\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{5}{8}$	$2\frac{1}{2}$	$2\frac{1}{2}$	...	...	$2\frac{5}{8}$	3	7	$3\frac{4}{16}$	$1\frac{4}{16}$
	503.0	117	0	31	0	37.18	5	$2\frac{7}{8}$	$2\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{1}{2}$	...	...	$2\frac{3}{4}$	3	9	$3\frac{7}{16}$	$1\frac{4}{16}$
	550.0	122	0	32	0	40.05	5	3	$2\frac{7}{8}$	$2\frac{7}{8}$	$2\frac{3}{4}$	$2\frac{5}{8}$	...	...	$2\frac{13}{16}$	3	11	$3\frac{10}{16}$	$1\frac{6}{16}$
	600.0	126	4	32	8	43.30	5	3	3	$2\frac{15}{16}$	$2\frac{15}{16}$	$2\frac{3}{4}$	...	...	$2\frac{15}{16}$	4	0	$3\frac{15}{16}$	$1\frac{7}{16}$
	708.0	134	0	34	3	49.23	6	3	3	3	$2\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{3}{4}$	...	$2\frac{7}{8}$	4	2	$2\frac{14}{16}$	$1\frac{6}{16}$
	824.0	142	0	35	10	55.90	6	$3\frac{1}{8}$	$3\frac{1}{8}$	$3\frac{1}{8}$	3	3	$2\frac{15}{16}$	...	$3\frac{1}{16}$	4	2	$3\frac{12}{16}$	$1\frac{1}{2}$
	921.0	148	0	37	1	61.45	7	$3\frac{1}{8}$	3	3	3	$2\frac{7}{8}$	$2\frac{7}{8}$	$2\frac{7}{8}$	$2\frac{15}{16}$	4	4	$3\frac{1}{4}$	$1\frac{1}{2}$
	1032.0	154	0	38	6	67.74	7	$3\frac{1}{4}$	$3\frac{1}{8}$	$3\frac{1}{8}$	$3\frac{1}{8}$	$3\frac{1}{8}$	3	3	$3\frac{1}{8}$	4	4	$3\frac{1}{2}$	$1\frac{5}{8}$

The length of the Pintles is commonly about three times their diameter, and the lower one about three and a half or four times its diameter.

Having given the above rules for proportioning the rudder, it will be necessary to notice some improvements, of which a few have been offered. Mr. Goldie's improvement is generally known, but I am not aware that it has been generally adopted. In order to prevent the numerous accidents to which ships are continually exposed in beating off or unshipping their rudders when driving over shoals or sands, or by striking the ground when entering harbours, he proposed fixing an additional piece of timber across the lower end of the rudder, keeping the principal pieces of which it is composed about 16 or 18 inches shorter than is commonly done, and at the bottom of these to fix a piece with only two bolts, and clamps of thin wood on each side, the piece being scarphed to the main pieces in a bevelled manner; so that, upon the vessel's striking the ground, this additional piece will come away, and leave the rudder in every other respect perfectly free from damage. A farther improvement on this principle has been proposed—to make the lower part of the rudder to slide up, on its striking against the ground.

Another improvement on the construction of the common rudder is to make the upper part, or stock, cylindrical, and to give it a cast forward, so that the centre of the cylindrical part shall coincide with the line of rotation, *i. e.* the centre of the pintles, or pins on which the rudder turns. The advantage of this improvement is, that as the centre of the cylindrical part which passes up through the counter or stern of the vessel is its centre of motion, its transverse section being a circle revolving on its axis, it

admits the rudder-case to be circular, and nearly of the same diameter as the stock; and this closeness of fitting prevents the sea from washing up the rudder-case—an object of great importance in large vessels. In order that the rudder may be easily shipped and unshipped, *i. e.* taken off its hinges, the rudder-case must be made of a greater diameter than the stock; and, to make it tight, a circular rim of wood, equal to the diameter of the stock, is nailed on the counter at the under part of the rudder-case.

A Mr. J. Rorie has suggested a sort of duplicate rudder, which should be always at hand, and ready to be applied whenever the principal rudder is damaged by any accident. He proposed to have a broad iron rudder, made to revolve or turn after it is let down through the dead-wood and keel at the stern. It has considerable ingenuity. Although a vessel possesses greater security from having a duplicate rudder, yet as it is attended with a considerable additional expense, and more liable to be damaged than the common one, it is not probable that it will ever be generally adopted. It is not applicable to coasting vessels.

The following is Captain Timbrell's method of closing the opening between the corner of the stern-post and fore-edge of the rudder, which is caused by the fore part of the rudder's edge being bearded away, to allow it to go over in steering the ship. The sides of the stern-post are made up to the flush of the rudder-bands, by a feather-edged piece of wood; the fore part of the rudder is also made up flush with the rudder-bands, in the same manner. There is then nailed on the stern-post a long sheet of copper, reaching from the load-water mark down to the keel; at the after-edge of this, and exactly at the corner of the stern-post, is hinged another long stripe of copper, which folds against the rudder, and thus covers the triangular opening between the stern-post and the rudder, and at the same time allows the rudder to go backwards and forwards, the loose flap sliding on the rudder.

There is also another improvement on the rudder, which produces the same effect as Captain T.'s flaps, which is, to make the rudder round on the fore-edge, so as to work into a corresponding hollow in the after-side of the stern-post. But these will be more particularly described in the practical part of this work, where directions are given for making and hanging the rudder.

Mathematicians have attempted to prove that the most advantageous angle at which the rudder can be placed, so as to turn the ship, is about 45 degrees from the centre line of the keel prolonged. Experience, however, proves that this angle is too great, and that 34 degrees is quite sufficient, and will have more effect in turning the ship. Few vessels have more than 33 degrees, or three points of the compass. That a less angle will have more effect in turning the ship than a greater, may at first appear inconsistent; but when we consider that the action of the rudder, to turn the ship on her centre of motion, is proportional to the velocity with which the vessel is sailing, and that if the angle of the rudder be great, the velocity of the ship will be much retarded, the inconsistency vanishes; and it must be evident, that a great angle of the rudder will have more effect in retarding the direct motion of the ship than a small angle. It also produces less effect in turning the vessel round on her centre of motion, because

the resultant of the force of the water on the rudder will be more in the direction of the ship's length than at right angles to the keel, so as to push the stern round.

Let the figures 114, 115 (*Plate* VI.) represent the section of a vessel at the line of floatation. Suppose the direction of the ship's motion to be B A, or the direction of the fluid A B; let A B be the centre line of the keel, which is prolonged to D; let B C (*Fig*. 115) be the rudder, forming the angle C B D, equal to 45 degrees; also let B C be the rudder in *Fig*. 114, forming the angle C B D, equal to 70 degrees. Now, as the vessel is sailing forward, the rudder is made to present an oblique surface to the action of the fluid; it would therefore be driven from this position, and fall in the direction of the keel; but this cannot take place, as the rudder is held in its inclined position by the man at the tiller, and the stern of the vessel is pushed about, and describes the arc B *d*, while at the same time the bow describes the arc A *b*, the vessel being supposed to turn on the centre of gravity G.

Again, as the vessel is moved forward through the water, it acts upon the rudder with an effort as the squares of the velocity multiplied by the square of the sine of the angle of incidence K E B or C B D. This being the effort of the fluid upon the rudder, we may resolve it into two forces, the one acting in the direction E L, and the other in the direction E J. The whole effort of the water, however, on the rudder, is represented by the diagonal of these forces, E F. The line of direction of the effort of the fluid upon the rudder is I E F; and according as this direction is farther from the centre of gravity G, so is the effect of the rudder to turn the vessel round increased. If we complete the parallelogram E *a* G I, then I G shall represent the leverage action of the rudder to turn the vessel round; but the action of the water is diminished as the angle C B D is lessened; therefore, although its leverage action is increased, there is less action of the fluid upon it. And when it is turned to a great angle, as *Fig*. 114, though its leverage power is diminished, yet there is a greater action of the fluid upon it; and hence there must be a certain angle which gives the maximum effect, and this is the angle of 45 degrees; because with this angle the rudder tends to turn the vessel round, and prevent her head motion with the same power, E J and E L (*Fig*. 115) being equal. Thus, then, it appears that the angle of 45 degrees would produce the best effect in turning the vessel quickly round.

But it is found by experiment that this is too great an angle, and that the rudder has the best effect in bringing the vessel quickly round when it tends less to stop her head-way than to push her round; and this in the angle of 45 is equal—that is to say, at that angle of the rudder, it tends as much to stop her head-way as to push the stern round. In general, the best angle for the rudder, to bring the vessel about, is between 34 and 37 degrees, according to her particular construction, for some vessels require a small degree more or less angle of the rudder to bring them about in the least time.

In the course of my practice, I have never bearded the rudder-stock more than 1-3d of its thickness down the side, which allows the rudder to form an angle of about 35 degrees, and which I believe is found to be quite sufficient for any vessel. A greater angle than this would do more ill than good, as the head-way of the vessel would be the more retarded, and the action of the fluid on the rudder reduced thereby.

Description of the Instruments, and Explanation of the Principal Curves used in Ship-Draughting.

The chief instruments consist of compasses, ivory scales, parallel rulers, drawing-pens, &c. which may be had at the different mathematical instrument-makers—thin pieces of wood, of various forms and shapes, having their edges rounded to parts of circles, ellipses, parabolas, &c. They should be made quite fair, and are used for guiding the point of the pen or pencil, so as to produce a proper curve on the paper. On the back of the construction plan (*Plate* XII.) are represented all the moulds that are required to draw the plans of the vessels given in this work.* A pair of proportioning compasses will be found of use in transferring plans from one scale to another.

The paper should be fastened on a square board, and a T square used for raising the perpendicular lines. They should be made of well-seasoned mahogany, and no cross heads should be put upon the board. The one half of the stock of the square should be made to turn upon a screw, so that by applying the shifting side of the stock to the edge of the drawing-board, the blade of the square may be so shifted as to form any angle to the sides or ends of the board. With a square like this, a parallel ruler is unnecessary.

The plans and working drawings of a ship, if complete, should exhibit her form and construction, and the form or curve of all the principal timbers, and situations of the different wales, planks, &c. From the working drawings, the dimensions of all the different parts, the curve and bevels of the timbers, &c. and their place in the ship, are obtained.

Owing to the curving and varying form of vessels, the drawing of their working plans is more difficult than most other mechanical drawings. If the boundaries of all the sections of a vessel were regular curves, such as circles, ellipses, parabolas, cycloids, or any other regular curves, it is evident, that by applying the rules for constructing these curves, we might proceed with some degree of certainty if we had the proper dimensions of length, breadth, depth, &c. without much chance of falling into error. As this is not the case, however, we must act with very great caution and perseverance in correcting one line by another, which are produced by different sections, some cutting the vessel horizontally from stem to stern, at different heights—some cutting her transversely to her length, and perpendicularly to the keel—some cutting her by a diagonal plane extending from stem to stern horizontally, but at the same time inclining upwards into the centre of the ship's breath—some cutting her vertically to the keel, but inclined towards the bow or stern, &c.

We shall now explain the nature of these sections. The drawing E (*Fig.* 116, *Plate* VI.) which represents the length and height of the ship, is called the elevation or sheer draught; that which represents the length and breadth, *Fig.* P, is called the plan, which represents the breadth and depth; *Fig.* B is called the body-plan, or plan of projection. It is taken from a section whose plane is at right angles to the keel, *i. e.* $b\,a$ is at right angles to $c\,d$, and also at right angles to the centre line of the ship, as $f\,g$ is

* The Reader may either construct a set for himself, or be furnished with one by applying to the Author, Leith.

at right angles to *h i*. The bottom of the vessel on each side of the line *b a* tapers gradually towards the stem and stern parts, and consequently, as the section at that spot is the greatest, all others may be inscribed within it. As the dotted curves in *Fig.* B represent a section at the line *l l* (*Figs.* E and P), the greatest transverse section, is marked ⊕; and the frame made for that spot is called the dead-flat frame. The rules for drawing and forming this frame, which regulates the general form of the bottom, will be afterwards pointed out.

The sections which cut the vessel horizontally from stem to stern are simple, and may be easily understood. The curves which these sections form, according to the shape of the vessel's bottom, are called water-lines, from their exhibiting the form of the vessel's bottom at the surface of the water, when she is immersed to any depth, and their plane is parallel to the keel when the vessel draws the same water at the bow and stern; but when the vessel is to swim by the stern, the plane of the water-lines is not parallel to the keel. The water-lines are drawn about two feet apart on the sheer-plan, and are marked 1st, 2d, 3d, &c. water-lines, from the keel upwards to the water-line, at which depth the vessel is supposed to float with a cargo. This one is called the load-water line, and the water-line about the depth at which the vessel is supposed to float when the cargo is discharged, is called the light water-line, and their plane is shewn in the different sections by *Fig.* 117. The water-lines should have no inward hollow at the fore-end, but may have a small inward hollow at the after-end. Their plane is indicated by dotted lines on the sheer or elevation plan, marked 1, 2, 3; also on the body plan B, marked 1, 2, 3; and the curve of the vessel's bottom is represented by the dotted lines 1, 2, 3, on the floor plan, marked F P.

Ribband-Lines.—These lines are formed by the extremes of a section which cuts the ship from stem to stern, but whose plane at the same time is inclined in its transverse position. Suppose A (*Plate* VI. *Fig.* 118) to be the midship section of a vessel, the plane of a water-line at the point *a* is *a c*, but the plane of a ribband-line at the same point *a*, is *a b*; and this being the diagonal of the rectangle *a c b*, it is called the diagonal ribband-line plane. Now, suppose we cut the ship down the middle line to the distance *d b*, and from stem to stern, as represented by the cut *c d f b b b b e*, *Fig.* E; again, let her be cut from the point *a* (*Fig.* A″) up to the middle line, in the direction *a b*, then it is evident that the portion *a b d g* (*Fig.* A) may be taken away, as represented in the transverse section, *Fig.* B, and in the elevation by *Fig.* E; *a′ b″* (*Fig.* E) should be equal to *b* (*Fig.* B.) Now the extreme edge *a a′ a″ a‴* of the diagonal section is the diagonal ribband-line; and this is measured in the direction of its plane *b a′ b′* (*Fig.* A or E), and extended from the centre line of the floor plane, *Fig.* 4, where it is represented by the curve *a a′ a″ a‴*. The dotted curve is supposed to be a water-line, whose plane is *a c* (*Fig.* A.)

There is another species of ribband-lines called level ribband-lines, but which are nothing more than the square measurements of the diagonal ribband, extended on the floor plane in the same manner as a water-line, with this difference between a level ribband-line and a water-line, viz. that the plane of the level ribband-line is bent downwards in a fore-and-aft direction, as *a a′ a″ a‴* (*Fig.* E), whereas the fore-and-aft plane of a water-line is straight.

The Buttock-lines.—These are formed by the extremes of sections which cut the vessel lengthways by a vertical plane. Suppose A (*Fig.* 119, *Plate* VI.) to be the midship section, and *Fig.* B the half plan of a vessel; now let us cut the vessel by a vertical plane *a b* (*Fig.* A), and *a a′* (*Fig.* B), we may then remove the piece *d d′* (*Figs.* A & B), and we shall have the elevations represented by *Fig.* C. The edge of the section *b b′ b″* is called a buttock-line, as it is seldom run farther forward on the plan than *b′*, it being chiefly used for fairing the buttock. It is evident that we may have a great number of them, by beginning at the outside of the vessel and cutting her into slides; the more cuts you have, the more buttock-lines will be formed, and the nearer you approach the centre-line of the ship, the nearer the buttock-lines will resemble the profile of the ship as formed by the stem, keel, and stern-post.

We have now shewn how the water-lines, ribband-lines, and buttock-lines are derived, by their different sections taken from the vessel as a solid, and the object will be to draw these lines in their due relations to each other, so that the surface and bottom of the vessel shall be faired, by producing fair curves in any section that may be desired.

On the Sheer of Vessels, and Position of the Midship Frame.

By the sheer, is meant the vertical curving downwards of the upper works of the ship, which is intended to make her more lively at sea, and increase her stability.

Almost all ships are broader in the middle of their length than at the ends; they have their bottoms more inclined from the horizontal position, before and abaft the midship or dead-flat frame, at every part, as it is nearer the stem and stern-posts; and therefore the ends of the vessel are heavier than an equal length in their middle, in proportion to their capacity. It has been shewn that the vessel is buoyed up by the vertical pressure of the fluid on those parts of the bottom that are more or less inclined from the vertical position. Hence it follows that there will be a great upward pressure at the middle of the ship, while at the same time there will be very little at the bow and stern, even less than is sufficient to float these parts at the same height out of the water. Now the great weight of the bow and stern, which is unsupported by the upward pressure of the fluid, will cause the bow and stern to fall or settle down to a certain extent, while the middle of the ship will bend upwards; and it is evident that if a vessel were not sufficiently strong to resist these strains to a certain extent, she would be useless. Even the strongest and best constructed vessels which have the greatest parts of their cargoes placed in their middle, get more or less hogged. It is hardly possible to build a vessel, however strong, that will not become more or less hogged in a short time.

If we take *Fig.* 120, *Plate* VI. to represent a sharp-raking vessel, and make G the centre of gravity, and C the centre of displacement; then the force of gravity on the vessel, concentrated in G, tends to sink her, but the vertical pressure of the fluid, concentrated in C, and which is equal to the whole weight of the vessel, is tending to raise her up; and these two forces being equal, opposite, and in the same vertical line, mutually destroy each other, and the vessel remains at rest. If she is sufficiently strong, no distortion of her form takes place; but as ships cannot be made sufficiently strong so as to withstand those forces to which they are exposed, without bending or straining in some

place or other, (although in many vessels the change of form can hardly be observed), it will be necessary to see how this bending upwards takes place. Let us consider the vessel divided by the vertical line C G, and that g is the centre of gravity of the fore-half, and f the centre of immersion of the same; that g' is the centre of gravity of the after-half, and e the centre of displacement; now the forces g and g' tend downwards, and the forces f and e tend upwards, and as they are not in the vertical line of the centres of gravity of the half of the ship, but are nearer the middle, it follows that the bow and stern will settle down, while at the same time the middle will rise up, so that the keel, in place of being straight, will become curved upwards, as represented by the dotted line; and for a similar reason, the vessel will lose her sheer in the same proportion. It will be seen that the sheer will oppose this bending upwards, provided the vessel has a proper tie, in the same manner as the arch of a bridge prevents it from falling down.

The bending of the vessel is supposed to take place similar to the bending of any beam of timber, and therefore that there is a certain point above, which all the fore-and-aft bindings are suffering extension, and that all the plank, keel, kelsons, and other longitudinal bindings which are below the neutral point, are suffering compression; therefore all the stringers and other fore-and-aft bindings above this point (which is supposed to be about one-third of the ship's depth above the keel) should be hook-scarphed together at their butts, and laid as parallel to the keel as possible, so that the vessel would be completely tied together, and the ends thus prevented from falling outwards. There should be pieces of hard timber driven in endways between the timbers of the bottom, so that the resistance to compression may be increased as much as possible, and the vessel ultimately prevented from hogging, which destroys the curving of the bottom in a fore-and-aft direction, and otherwise damages and distorts the appearance of the ship.

On the Position of the Midship or Dead-Flat Frame.

It has been much disputed by builders which is the proper situation on the keel for the dead-flat frame. Some insist that its proper place is at the distance of 2-3ds of the length of the vessel from the stern-post on the line of floatation; others think this too far forward, and that it should be placed only a very little before the middle of the ship. Theory is in favour of the former opinion, and experience in favour of the latter; for it is found that vessels having their flattest floor, or the flattest part of their bottoms, in their middle, or nearly so, are fast sailers, and much superior to those whose bottoms are carried far forward. This may account for the fast sailing of those vessels which have been built by persons who had no theoretical knowledge but what they derived from their observations on the sailing of vessels.

But as to the situation of the dead-flat frame on the keel, I am inclined to think that it is generally placed too far forward, and that it should not be farther before the centre of the ship on the line of floatation than 1-15th of her length. Many persons imagine that the form and position of the midship frame will regulate the rate at which the vessel will sail; but this is incorrect, for it is perfectly certain that the sailing depends on the form of the entrance and run. The midship frame may be of almost any shape, but

if the bottom of the vessel be in other respects regularly framed, and possess a proper entrance and run, she will sail fast.

Before concluding this chapter, I shall explain the manner of draughting a small vessel, which will make the reader sufficiently acquainted with the various lines, so as to enable him to construct an original plan from the directions and rules to be explained in the following chapter.

Sketch of the Process of Drawing the Plan of a Vessel,

Intended to prepare the Reader for what follows in the next Chapter.

Having procured a drawing-board of mahogany, or American fir, and all the necessary instruments, moulds, &c. take a sheet of paper large enough to hold the plan of the vessel on a quarter or 3-8th inch scale. If the vessel be below 100 tons, a 3-8th scale will be the most convenient. Damp the paper regularly; then fasten it to the board by rubbing a little glue round the edges of the paper, pressing them close down to the drawing-board; allow it to stand for an hour or two, until the paper is quite dry. (See *Plate* XIII.) The first thing after the paper is quite dry is to construct the scale of feet and inches; then commence to draw the sheer-plan, or outline of the ship's length and height, &c.; and having all the dimensions calculated, draw a straight line *a a* for the upper edge of the keel; at the depth of the keel, below that, draw another line for the lower edge of the keel; at about the middle of the paper, draw a perpendicular line *b b*, and measure from this line, along the keel, half the ship's length for tonnage, and at that distance draw the perpendicular *c c*, which will be the front of the main stem at the bowsprit; and from this perpendicular, measure aft, upon the upper edge of the keel, the exact length of the vessel for tonnage, and at that spot square up another perpendicular line *c′ c′*; and, exactly where it cuts the upper edge of the keel, must be made the after-part of the stern-post at the keel. Having done this, next draw vertical lines at ⊕ A C F H J K L, and these will be the vertical planes of the frames of the fore body; draw the vertical lines 2, 4, 6, 8, 10, 12, 13, 14, 15, and 16, for the planes of the frames and timbers in the after body; draw a horizontal line as far below the upper edge of the keel as the thickness of the plank of the bottom or garboard-strake; mark the fore-end of the keel as at L, and take a proper mould, and draw the stem according to the intended rake, making the lower part to reconcile with the upper edge of the keel; draw with the same mould another line, without the inside line of the stem, the thickness of the plank, and make it to reconcile with the former drawn line below the upper edge of the keel. This part of the keel and stem, contained between these two lines, is cut out like a V, and forms a rabbet to receive the edge of the garboard-strake at the keel, and the ends of the planks at the stem. At the end of the keel erect the stern-post, and draw a line three inches abaft its fore edge, for the rabbet of the stern-post; next draw the sheer-lines to their proper height, as the line *f f* for the lower edge of the bends, *h h* for the under side of the main gunwale, or top-height line; next mark the height of the wing-transom W T; draw the counter *d d′*, and stern *d′ e*; draw the line *k k* for the lower side of the rail, and

give these sheer-lines a small rise, from about frame J, forward to where they end at the rabbet of the stem, as at *i i i*; then draw the water lines *n n' n''*.

The sheer-plan being thus sketched in, we may next proceed to draw the body and floor-plane. For this purpose, draw the centre lines *a' a'* and *a'' a''*; these of course must be exactly parallel to the keel. Square down the vertical line *b b*, as *b' b'*, for the centre line of the body-plan; on each side of it set off the half thickness of the stern-post or stem, and draw the vertical lines *q q* and *q' q'*, having the half thickness of the stem and stern-post; in the compasses set off the same from the centre line of the floor-plane forward and aft, and draw the line *q* and *q'* parallel to *a' a'*, the centre line of the floor-plane.

Proceed now to erect the midship or dead-flat frame, marked ⊕. First take the exact half breadth of the vessel, exclusive of the thickness of the plank, and set it off from the centre line of the body-plan upon the line *a'' a''*, and then draw the vertical lines *r r*, *r' r'*. The horizontal line upon which the body plan is erected is called the base-line, as it represents the transverse plane of the upper edge of the keel. In drawing the midship-frame, observe that it coincides with the perpendicular lines *r r* and *r' r'*, about the height of the load-water line, *i. e.* the upper water-line on the plate, marked *n*, and above which the side is carried quite vertical and straight, between the dotted line marked *m m* and *l l* in the sheer-plan, and that above the height of the line *l l*; the top part of the frames inclines inwards towards the centre of the ship. (*See the body-plan.*) Now, the dotted line marked *m m'* is called the lower height of breadth line, and the other, marked *l l*, is called the upper height of breadth line.

We may now proceed to draw the main-breadth line on the floor-plane, which terminates at the stem on the sheer-plan, where the upper height of breadth line *l l* cuts the rabbet of the stem, *i. e.* at the point *p*; therefore, to find the termination of the main-breadth line on the floor-plane, square down the point *p* in the sheer-plan to *p'* in the floor-plane, and having marked off the exact half breadth of the midship frame from the centre line of the floor-plane at ⊕, take a regular sheer-mould, and draw the line *o o' o''* to about as far forward as frame H; then with a proper mould draw the round part or bow, as *o p*; in like manner, draw the top-breadth line on the floor-plane, *i. e.* the line *u u* in the floor-plane, which represents the line *h h' i* in the sheer-plan. In drawing the plan, it is only necessary to represent one half of the frames on the body-plan, or one side of the vessel in the floor-plane, the other being exactly the same. The main-breadth line *o o' o''* gives the extreme breadth of all the frames from the stern to the frame H, before which the top-breadth extends without the main-breadth, to give a flanging-out form to the bow.

Having the main and top breadth lines drawn on the floor-plane, and having the midship-frame drawn on the body-plan, we may next draw the plane of the diagonal ribband-lines (which we call the diagonals) in the body-plan, *i. e.* the inclined lines *t t*, &c. (The rules for placing these, and for proportioning all the other parts, are given in the next chapter.) Take the rise of the ⊕ frame at the intersection of the second diagonal above the base line of the body-plan, and set this up from the upper edge of the keel at frame ⊕ in the sheer-plan; then take the height of the second diagonal

from the keel upwards, above the base-line, to where the diagonal cuts the side-line of the stem and stern-post, and mark this height perpendicularly above the line of the upper edge of the keel on the stem and stern-post in the sheer-plan; draw from the spot on the stem a regularly curving line aftwards, passing through the spot made on frame ⊕ to the mark of the diagonal on the stern-post. This line is called the rising line (see the sheer-plan), and it runs nearly parallel to the lower height of breadth line, *i. e.* the dotted line marked *m m*. The curve of the rising line is quick at the stem, but gradually flattens in the midships, and becomes more straight as it approaches the stern-post. The rising line being now drawn, we may commence to draw the frames of the fore or after body on the body-plan. Those on the right side of the centre line represent the frames of the fore body, and those on the left the frames of the after body. Suppose we begin to draw the frames of the after body, neglecting to draw frame 2, because it is so near to ⊕, (the fore-and-aft curvature of the vessel varying so little in midships, upon so short a distance, would bring frame 2 quite close to the midship-frame in the body-plan), beginning with frame 4. Thus, take the exact height above the upper edge of the keel where the rising line cuts frame 4, setting the same up from the base-line of the body-plan to where it cuts the second diagonal; and then from this spot draw the frame straight into the side of the keel at the rabbet. Next measure the height of the lower height of breadth line at frame 4, in the sheer-plan; set this up from the base-line of the body-plan; take the upper height of breadth, set this up from the base-line of the body-plan in the same manner; the top-height of frame 4 must be transferred from the sheer to the body-plan; then taking the main breadth of frame 4, (*i. e.* the distance from the centre line of the floor-plane to where the main breadth line cuts frame 4), set this off level from the centre line of the body-plan, and at that spot square up a perpendicular line between the lower and upper height of breadth, this much of the frame being quite straight and upright. Mark the top-breadth on the top height line, and draw the part of the frame above the upper height of breadth. Having done this, take a mould nearly of the same curvature as the one which drew the bilge part of the midship-frame, only a little flatter, and draw the bilge or round part of the frame between the second diagonal and the lower height of breadth, making the curve to reconcile with the upright part of the side and straight part of the bottom or floor. In the same manner are all the other frames 6, 8, 10, &c. sketched in; and when all the after body frames are drawn, proceed to those of the fore body, and sketch them in the same manner, and draw the frames to be quite fair, and to have no bumps or quirks from the keel to the top. The dotted frames or sections marked K and L, in the fore body, and 13, 14, 15, and 16 in the after body, are called trying frames, as they are not intended to be made into frames, but are merely used to form and adjust the ends of the vessel, and to guide the ribband and water-lines near the stem and stern-post frames. J and 16 are called the foremost and aftermost square fames.

Now, the ship may be quite fair, according to the sections or frames in the body-plan, while at the same time she may be very unfair in a fore-and-aft direction. We therefore proceed to run the ribband and water-lines in the floor-plane, and to alter any of the frames in the body-plan which may require the same, in order to make the

ship fair in the fore-and-aft direction, as well as in an up-and-down direction. For this purpose, we may run the water-lines first, as they are more simple than the ribband-lines. The plane of the water-lines must therefore be drawn on the body-plan, at exactly the same height above the base-line as they are above the upper edge of the keel in the sheer-plan; and the water-lines being parallel to the keel in the sheer-plan, are parallel to the base-line in the body-plan. Now, suppose we run the lower water-line, *i. e.* the one marked *n*", and to find its termination, square down where it cuts the inside and outside of the rabbet of the hoods at the stem and stern-posts in the sheer-plan, to the centre line of the floor-plane; *i. e.* the point W on water-line *n*" in the sheer-plan is squared down to the half thickness line of the stem and stern-posts in the floor-plane. Thus the termination of the water-line in the floor-plane being found, proceed to measure the horizontal breadth of all the frames from the centre line of the body-plan, on the plane of the water-lines, and transfer these distances from the centre line of the floor-plane on their respective frames in the same, and through all these spots draw the water-line. Measuring the breadth of the frames at the plane of the water-line, and transferring them to the floor-plane, is done in this manner:—Make the distance *x y* in the floor-plane equal to *x y* in the body-plan; *x z* in the floor-plane equal to *x z* in the body-plan, and so on with all the other frames in the fore and after body; and then through all these spots *y z*, &c. &c. in the floor-plane, draw the dotted line *n*", and it is the first water-line in the floor-plane. The first water-line being drawn on the floor-plane, the others are pricked off from the body-plan, and drawn in the same manner. These lines must be made to run quite fair, and the frames in the body-plan altered to correspond, if necessary.

Some builders fair the frames entirely by the water-lines, and therefore have a great number of them, one every foot or 18 inches from the keel upwards to the load-water mark. But as the planes of the water-lines cross the frames very obliquely, they cannot be so correctly measured off as the ribband-lines, as the least variation in their true height on the body-plan makes a great difference in the measurement. If the point of the compasses be not placed exactly on the water-line at the frames, it will not be the true breadth. It will be observed, that as the plane of the ribband-lines crosses the frames nearly at right angles, it is more easy to take their measurement correctly; and there are also many other considerations, of a more important nature, which recommend the use of the ribband-lines, and render them of more importance than the water-lines, all which will be afterwards fully explained.

In making a correct plan, we also employ the ribband lines for fairing the timbers in a fore-and-aft direction, and they are run on the floor-plane thus:—First, take the exact height where the first diagonal in the body-plan cuts the side of the stem (*i. e.* the distance from the base-line up to the mark &); set this height up from the upper edge of the keel on the stem and stern-posts in the sheer-plan, and draw a line across the rabbet of the stem and stern-posts, parallel to the keel, *i. e.* the short line in the sheer-plan at the stem and stern-posts, marked &; next square down to the centre line of the floor-plane, the exact spot where this short line cuts the inside and outside of the rabbet of the stem and stern-posts, the inside being marked 1 and the outside 2,

(*see the floor-plane*), and find two spots on the stern-post in the floor-plane in the same manner; next proceed to the body-plan, and take the diagonal half thickness of the stem and stern-posts, that is, the small distance *t*, &c.; set this from the centre line of the floor-plane on the outside mark of the rabbet, both at the stem and stern, *i. e.* on the mark 2 (observe a small point on this line at the diagonal, half the thickness of the stem); take the thickness of the plank in the compasses, and on this point as a centre describe a semicircle inwards (observe the dotted semicircle on the plate), and this gives the ending of the ribband-line at the bow; and the same being done at the after-end, gives the ending of the ribband-line at the stern-post. Having the termination of the ribband-line, proceed to measure it off from the body-plan thus: Beginning with the fore body first, set the point of the compasses in the centre line of the body-plan where it is cut by the first diagonal; measure from this, down in the direction of the diagonal, to where it is intersected by frame L; then set this off from the centre line of the floor-plane on frame L; proceed to the body-plan, and take the distance from the centre line down the first diagonal, to where it is intersected by the next frame, which is K.; set this off from the centre line of the floor-plane on frame K, which happens to be the point *y*, and proceed to the body-plan, and take the distance from the centre line down the first diagonal, to where it is cut by frame J; set this off from the centre line of the floor-plane in the same manner as upon frame J, and so on with all the other frames in the fore and after-body. Then through all these points in the floor-plane draw the first diagonal ribband-line *t t'* in the floor-plane; and in like manner proceed to find the termination at the stem and stern-posts of the next, and all the other diagonal-ribband lines, and prick them off from the body-plan to their respective frames in the floor-plane in the manner now pointed out.

All the water-lines and ribband-lines having been drawn, and the frames constructed, we may now proceed to draw the buttock-lines. First, draw their cutting planes in the body-plan, *i. e.* the vertical dotted lines marked 1′, 2′, 3′, 4′, in the after body frames, and with the same distances in the compasses turn them the same number of times from the centre line of the floor-plane upon any of the after-frames, and at these points draw lines forward parallel to the centre line, and we then have the cutting plane of the buttock-lines on the floor-plane; these are called simply the buttock-lines in the body and floor plans. The next thing is to prick them off from the body-plan to the sheer-plan: First draw a perpendicular line, down from where the wing-transom cuts the inside of the stern-post, to the floor-plane, and draw W T, the wing-transom in the floor-plane; this being done, take the distance of the wing-transom before the perpendicular line just drawn, where it is cut by the first buttock-line in the floor-plane, (*i. e.* the one next the centre line), and set this from the inside of the stern-post on the sheer-plan on the line of the wing-transom, and this is the spot where the first buttock-line will pass across the wing-transom in the sheer-plan. Proceed to the body-plan, and take the exact height from the base-line, on the first buttock-line marked 1′, up to where it cuts frame 16, and transfer this height above the upper edge of the keel on frame 16 in the sheer-plan. Proceed again to the body-plan, and on the same buttock-line 1′, measure from the base-line up to where the buttock-line is cut by the next frame, which is 15; set this

height on frame 15 in the sheer-plan; again return to the body-plan, and take the height of frame 14 on the first buttock-line, and transfer this to frame 14 in the sheer-plan; take the height of frames 13, 12, 10, and 8, on the first buttock-line, and transfer these heights to their respective frames 13, 12, &c. in the sheer-plan; we will thus have a number of points through which to draw the first buttock-line in the sheer-plan. This being drawn, proceed with all the other buttock-lines in the same manner; and by drawing the cutting plane of the buttock-lines in the fore body, and pricking them off in the same manner, we may draw the buttock-lines from bow to stern in the sheer-plan. Now the frames in the body-plan must be drawn so that they make the water-lines and ribband-lines run quite fair in the floor-plane, also the buttock-lines in the sheer-plan.

The next thing to be done is to draw the transoms. Their moulding or upper edges must be drawn in the sheer-plan; these are marked 1, 2, 3, and 4, and are parallel to the wing-transom, marked W T. Then the heights of the transoms are transferred from the sheer-plan to the body-plan, parallel to the base-line, and are marked W T, and 1, 2, 3, and 4. Proceed to draw them in the floor-plane, in which the wing-transom is supposed already drawn; therefore commence with the transom immediately below it, and which is marked 1; taking the distance from the perpendicular line (which was let fall from the seat of the wing-transom) to where the first buttock-line crosses transom 1, in the sheer-plan, and setting this from the said perpendicular line on the first buttock-line in the floor-plane, we have a spot through which the transom must be drawn. Proceed to the sheer-plan, and take the distance from the perpendicular line to where the second buttock-line cuts transom 1, and transfer this from the perpendicular line on the second buttock-line in the floor-plane; we thus find a point in all the buttock-lines in the floor-plane through which the transom must be drawn; and its termination at the stern-post is found by squaring down to the centre line of the floor-plane the exact spot of the transom on the inside of the stern-post in the sheer-plan; the transom is then drawn in the floor-plan, and in like manner is transom 2, 3, and 4, pricked off from the buttock-lines in the sheer-plan to those of the floor-plane, and drawn accordingly.

As the planes of the transoms in this plate are parallel to the keel, their intersection with the buttock-lines may be squared down to the buttock-lines in the floor-plane, in place of pricking them off with the compasses. After the transoms are drawn in the floor-plane, we may next draw the cutting plane of the fashion-timber, *i. e.* the inclined line O O″; and then, if we measure from the centre line of the floor-plane along this inclined line to where it is cut by the transoms, and set these distances from the centre line of the body-plan on their respective transoms, we shall have a number of spots through which to draw the moulding edge of the fashion-timber. The moulding part of the plan being thus prepared, we next finish the sheer-plan by drawing the rudder, placing the mast and bowsprit, &c.; also the deck-plan, shewing the position and number of the beams.

CHAPTER II.

DIRECTIONS FOR DRAWING THE MOULDING PLANS, SECTIONS, &c. OF MERCHANT VESSELS.

Having, in the preceding Chapter, made the reader fully acquainted with the technical terms of the art, with the laws of stability, and theory of the rolling and pitching motion,—the general dimensions of ships,—the principal sections into which the ship is supposed to be cut,—the names of the lines derived from these sections, and also with the general process of carrying forward the plan,—The following are the directions for constructing the whole of the moulding plans, sections, &c. for any merchant vessel, and for laying down the principal timbers according to the most correct rules.

On the Sheer-Plan.

The Sheer-plan is the first to begin with. It is to be understood that the general dimensions of the vessel, according to the trade she is designed for, or particular class to which she belongs, are agreed upon; such as the length for tonnage, the extreme breadth and depth of hold, the size of the floor-timbers, &c., and whether the vessel is to be on a burthensome or sharp construction.

From these dimensions, it will be known what size of paper will be required to hold the plan according to the scale you intend to work from. Having put the paper on the board, and constructed the scale, first find the proper height of the midship-frame, and all the other leading proportions of height, in this manner:—To the given depth of the hold from the deck to the ceiling-plank next the limbers, add the depth of the midship floors from the top of the rabbet of the keel to the under side of the kelson and the thickness of the ceiling-plank; then from that sum deduct the round of the main-deck beams, and to the remainder add the thickness of the water-way, or whatever standing work is to be above the deck—the sum will be the height of the midship-frame above the rabbet of the keel. According to this height all the others will be regulated. Thus the height of the load-water line, or line of floatation, at a moderate depth of immersion, is 5-7ths or 7-10ths of the height of the midship-frame; height of the wing-transom from 4-5ths to 5-6ths of ditto; height of the lower edge of the main-wales at ⊕ 3-5ths of ditto; height of the fore adjusting water-line 3-10ths of ditto; height of the after adjusting water-line 5-12ths of ditto. (See *Plate* XII.)

Having found all the leading proportions of heights, proceed with the sheer-plan. At about twice the height of the midship-frame, from the upper edge of the paper, draw a straight line parallel to the edge of the board, right along from end to end, to represent the upper edge of the rabbet of the keel; draw another line under it the thickness of the bottom plank, and exactly parallel to the first, for the lower edge of the rabbet of the keel; also draw another straight line parallel to the former for the

under or lower edge of the keel. Then, at the right-hand end of the paper, leaving about 1-9th or 1-10th of the whole length of the ship for a head (if to have one), draw a line perpendicular to the keel (as the dotted line marked *Foremost perpendicular*, *Plate* XII. *Fig.* 1), to represent the fore part of the main stem at the under side of the bowsprit, which is the part measured from in taking the length for calculating the tonnage. Next measure from this perpendicular line, along the upper edge of the keel, the exact length of the vessel for tonnage, that is, the length of the keel and the fore-rake of the main stem, and that will give the after part of the main stern-post at the keel, at which erect a perpendicular. To this length, add half the height of the midship-frame, and at that spot square up another perpendicular line, *(marked on the plate Aftermost perpendicular)*. From the foremost perpendicular to this last drawn line will be equal to the whole length of the ship aloft, sufficiently near for the present purpose. In the middle of the extreme length, erect another vertical line to the keel, and it will be nearly in the lowest part of the sheer-plan. Having the length thus measured off, set up the several heights above the upper edge of the keel; set on the middle perpendicular, the height of the midship-frame and height of the load-water line, and at these heights draw straight lines parallel to the keel from the aftermost to the foremost perpendicular; also set on the height of the lower edge of the main-wales, and the fore-and-aft-lines drawn at these heights will represent the height of the sheer-lines at midships, also the height of the load-water line, the vessel being supposed to float on an even keel.

Next set up the height of the fore edge of the main stem on the foremost perpendicular, which for sloops and smacks is nearly 1 and 1-3d times the height of the midship-frame, and in brigs or ships 1 and 1-4th times the height of the midship-frame. Having marked this height above the upper edge of the keel on the foremost perpendicular, set aft, at that spot, the moulding dimension of the stem, and commence to draw it in, observing to give the part above the load-water line a rake of 3 inches to the foot of height between the same and the under side of the bowsprit. Having thus marked aft from the fore perpendicular on the load-water line, the spots through which the stem must pass, draw it by a mould, which will bring the stem nearly to a straight at the top, and which will gradually increase the curving until it meets the line of the upper edge of the keel, forming a tangent to the curve of the stem at the point of contact.

The exact form of the curve of the stem is not supposed to be material; yet it is certain that a fine regular curving of the stem, from the load-water line downwards to to the keel, assists greatly in forming the entrance of the vessel. In the event of not being able to procure a proper piece of timber for this purpose when you come to build the vessel, any small alteration from the plan may be made on the form of the lower part of the stem, such as to make it less curving, by only making the fore end of two or three of the lower water-lines in the entrance a little more straight, which will not have any prejudicial effect on the sailing of the vessel. There are several methods used for drawing the stem; and in low flat vessels it will answer to sweep it with the compasses; but for high vessels, where the stem is to be of a straight form, it is best to trace the curve by the intersection of straight lines from the load-water line to the

keel, which may be correctly formed or drawn with an elliptic mould. In order to draw the intersecting lines, continue the line of the straight part of the stem above the load-water line down till it meet the keel, and divide it, from the keel to the load-water line, into any number of equal parts; also divide the space on the upper edge of the keel, between this line and the spot where it is intended to join the stem to the keel, into the same number of divisions, as shewn by the lines drawn for that purpose in *Fig.* 1, *Plate* XII., where it is divided into eight equal parts. The curve of the stem being thus traced, next draw a line for the outside of the rabbet, making it join well with the under edge of the rabbet of the keel; also draw the outside or fore edge of the stem; then proceed to draw the stern-post. Having the exact length marked off for the after side of the main stern-post at the keel, add to this the breadth of the false stern-post, if the vessel is to have one; at that spot draw up the aft side of the stern-post, with a rake aft of 2 inches to every foot of its perpendicular height; also draw up the inner side of the post, and a line for the rabbet, making the breadth, at about the height of the wing-transom, 2-3ds of the breadth at the keel.

With respect to the rake of the stern-post, I am aware that there are various opinions on this point. Some place the after side of the post quite perpendicular to the keel, because they suppose it is stronger and more proper. Some vessels, badly proportioned in the run, have had additional pieces put on, so as to lengthen out the run and make them steer. To save the trouble of altering the rudder-case, the piece is generally broader at the lower end than at the top, thus bringing the stern-post nearly upright. But this is certainly no reason why the stern-posts of all vessels should be so, for in most cases it would answer the same purpose if put on of an equal breadth. I have seen a vessel on whom this experiment to make her steer was tried without effect; but upon the broad end being put upwards, giving the post more rake than before, she answered much better, because she was rather full about the buttocks. In fact, if the run of a vessel be properly formed, either to an upright or raking stern-post, it makes no difference on her sailing or steering. The raking post is more easily fastened, and the heel-knee is more easily obtained, being straighter. This method is therefore stronger. Most of our very fastest vessels have a rake of the post of from 2 to 4 inches to the foot. The London and Leith smacks (about 200 tons register) are burdensome vessels; they have in general 3 or 4 inches to the foot of rake of the stern-post; and they steer and sail uncommonly well, and go but little by the stern. Some of them of late have been built with upright stern-posts, but I do not consider that they are improved thereby, either in steering or sailing, and they take much more room in staying or wearing.

The next thing is to draw in the sheer-lines for the top-height and the lower edge of the wales. Set a line square up from the spot where the load-water line cuts the inside of the rabbet of the stem, and at the perpendicular at the end of the keel at the stern-post. From the straight line which was drawn at the height of the midship-frame, set on these perpendiculars the rise of the intended main-sheer of the vessel, which for different sizes of vessels will be in the following proportions:—

The main-sheer on the top-height line, from the stem to the stern-post, is, for

A ship of 500 tons measurement, $\frac{3}{4}$ inch for every 4 feet of the length.

Ditto	400 do.	do.	$\frac{7}{8}$	do.	do.	do.
Ditto	300 do.	do.	$\frac{15}{16}$ or 1	do.	do.	do.
Brig,	200 do.	do.	1	do.	do.	do.
Smack,	100 do.	do.	$1\frac{1}{8}$	do.	do.	do.
Sloop,	50 do.	do.	$1\frac{1}{4}$	do.	do.	do.

And for intermediate sizes, in the same proportions. Having calculated the main-sheer, and set it off on the perpendicular lines, take a sheer-mould, and lay it to the spots at the stem and stern, with its belly or round part touching the tangent line at the middle perpendicular; draw the line marked *Top-sheer line*, *Fig*. 1. In the same manner draw the line marked *Lower edge of the wales*, giving it a little more sheer than the top-line; also draw the upper edge of the wales or bends, their breadth being commonly about 1-6th of the height of the midship-frame.

The position, or height and breadth of the bends, are sometimes varied a little, to suit the materials. Although 3-5ths of the height of the midship-frame is here pointed out for the height of the lower edge of the bends, it will be proper to notice that some builders place the bends very high on the vessel, from the opinion that it improves the general appearance, which may be true to a certain extent. At the same time, if the bends are placed too high, they do not strengthen the vessel at the proper place, and only serve to make her crank, by increasing the top-weight. The height of the upper edge of the wales should never exceed 7-9ths of the height of the midship-frame. In every case, they should be laid so that their lower edge is the breadth of a strake above water at the bow and buttock, when the vessel is loaded.

The next thing is to mark the height of the wing-transom on the stern-post, which is 4-5ths of the height of the midship-frame. At this height, draw a straight line across the stern-post, parallel to the keel, continuing it abaft the post to the aftermost perpendicular. Take 1-3d of the height of the wing-transom if for a small vessel, and 1-4th if for a large vessel, and mark the distance aft from the fore edge of the stern-post on the line of the transom, and at that spot square up a line to the top or main-sheer line. Divide it into three equal parts; the second above the level line of the transom is the knuckle of the quarter-timber for a smack or sloop; and for a brig or ship which is to have a flush deck, make the height of the knuckle of the quarter-timber 4-7ths or one-half of the height from the level of the transom to the main-sheer line. Again, if the vessel is large, and to have a poop of 5 or 6 feet above the line of the main deck, mark 1-4th of the height of the wing-transom from the keel up from the level line of the transom on the vertical line which extends from the same to the top-sheer line, and that will be the place of the knuckle of the quarter-timber. In small vessels, the height of the knuckle of the quarter-timber, from the upper edge of the keel, must not be less than the height of the midship-frame. Having marked the knuckle of the quarter-timber, draw in the stern above, so as to have a rake aft of 6 or 7 inches to a foot. Rather less than this will be sufficient for a large vessel, as $5\frac{1}{2}$ inches to the foot. Next, with a mould draw the counter, having a small hollow inwards; also draw up the after ends of the bends, so as to correspond with the hollow of the counter, as will be observed on the plate.

The sheer-plan being thus far sketched in, the next thing is to place the balance-frames, in order to proportion the entrance, midship body, and the runs, (*See Plate* XII. *Fig.* 1.) Divide the length of the load-water line, from the inside of the rabbet at the stern-post to the inside of the rabbet at the stem, into eight equal parts, as 1, 2, 3, &c.; at the third division from the stern-post, square up a perpendicular to the keel for the after balance-frame; through the 6th division from the stern-post, square up another line for the fore balance-frame; we shall then have 2-8th parts of the ship's length for the entrance, 3-8th parts for the midship body, and the remaining 3-8th parts for the length of the runs. The two balance-frames are made nearly similar, and have the same rising. The rising line between them (which represents the fore-and-aft round of the bottom in midships), has a round of about 1-8th of an inch for every foot of the distance between them. Some very flat-bottomed vessels have only a round of about 1 inch for every 10 feet of the distance between the balance-frames, which is considered rather little.

As the curve of the rising line between the balance-frames is nearly a fair circle, the centre between them is the station of the dead-flat floor, and consequently the station for the dead-flat frame, or midship-frame, is thus determined. If the dead-flat frame is placed in the centre between the two balance-frames, it will be 1-16th of the length of the ship on the load-water line before the middle; but as there is so very little round on the midship bottom of merchant vessels, the dead-flat frame may be placed at 3-7ths of the distance between the balance-frames abaft the fore one, which will make it stand 1-12th of the ship's length before the centre of the load-water line, which is the very farthest forward it should be placed.

After the balance-frames are drawn, proceed to place the fore and after adjusting frames, and to draw the height of the adjusting water-lines on the sheer-plan (*Plate* XII. *Fig.* 1). Take 3-10ths of the height of the midship-frame in the compasses, and mark it perpendicularly up from the upper edge of the keel, on the inside of the rabbet of the stem, and at this height draw a line aftwards, parallel to the keel; this will be the plane of the fore adjusting water-line. To place the after adjusting water-line, take 5-12ths of the height of the midship-frame, and set it up on the stern-post, and draw a line forward, parallel to the keel, for the plane of the after adjusting water-line. Then to place the adjusting frames, mark 1-4th of the breadth of the midship-frame aft from *e*, the inside of the rabbet of the stem; at that spot draw up a perpendicular line, and it will be the fore adjusting frame. For the distance of the after adjusting frame, take 1-3d of the breadth of the midship-frame, set it forward from the inside of the rabbet of the stern-post on the after adjusting water-line, and at that spot square up a vertical line for the plane of the after adjusting frame.

The object is to form these frames in due proportion. If we can form them to the proper fulness at the spot where the adjusting frames cross the adjusting water-lines, and then make the entrance, midship-body, and run, fair, and corresponding thereto, all the other parts of the work are merely labour—the formation of the whole bottom being regulated by the form and position of these five frames, *i. e.* the midship-frame, the two balance-frames, and the two adjusting frames. The point *e*, *i. e.* the inside of the

rabbet of the stem or stern-posts, from which the fore adjusting frame is measured aft, may be found by taking the height of the load-water line in the compasses, setting it aft from the inside of the rabbet on the load-water line, and then by sweeping it downwards, will give the point A on the adjusting water-line; and marking the width of the rabbet aft from this point will give the point *e*, from which the adjusting frame and angle of the water-line is to be set off, whatever may be the rake of the stem, *i. e.* whether the point *e* be the inside of the rabbet or not. For the same spot at the stern-post, place the point of the compasses on 1-8th of the length of the load-water line; extend the other to the seat of the wing-transom; sweep that down, and it will cut the adjusting water-line at the outside of the rabbet, as represented on the construction-plan, *Plate* XII.

Having the sheer-plan so far completed, as represented by *Fig.* 1, *Plate* XII., proceed to draw the floor-plane, as represented by *Fig.* 2. At about 2-3ds of the ship's breadth below the keel of the sheer-plan, draw a straight line parallel to the keel for the centre line of the floor-plane, and parallel to it draw the dotted line at the half breadth of the midship-frame (not including the thickness of the plank) from the centre line; this will form a tangent to the side, and limit the main-breadth line at ⊕. Square down to the centre line of the floor-plane the adjusting-frames, balance-frames, and the midship-frame; also square down the spot where the upper height of breadth line cuts the inside of the rabbet of the stem, which will give the ending of the main-breadth line at the stem in the floor-plane. From the spot where this perpendicular line from the main-breadth intersects the tangent-line to the side, draw the diagonal line, forming an angle of 45 degrees; divide it into 12 equal parts, as 1, 2, 3, 4, &c. and through the 8th division is to pass the main-breadth line. At the stern, about the seat of the wing-transom, draw a perpendicular line across the floor-plane, and divide it into four equal parts; through the third division from the centre line is to pass the main-breadth line, making the breadth of the vessel at the stern-post 3-4ths of the breadth in midships. Then, to draw the main breadth, take a sheer-mould that will just touch the tangent-line at flat, or a little before it, when its after-end is lying at the proper breadth aft, and draw the main-breadth forward to about the fore balance-frame; take a round-ended mould that will reconcile with the main-breadth at the fore balance-frame, and draw the round or bow part of the main-breadth, passing through the 8th division on the diagonal line. But if you wish to have a fine bow, draw the main-breadth line through 5-8ths of the diagonal line, which will make the bow a little sharper.

The next thing to be done is to set off the angle of the adjusting water-lines at the bow and stern. Square down to the centre line of the floor-plane the spot where the adjusting water-lines cut the inside of the rabbet of the stem and stern-post; then from the point *e*, at the centre line of the floor-plane, draw the straight line *e* D, so that the angle D *e* C will be 45 degrees, and where this line cuts the fore adjusting frame, is the spot through which the adjusting water-line is to pass, according to the degrees of sharpness of the entrance. The angle D *e* C will be varied according to the sharpness of the vessel, and the angle D′ *e*′ C′ at the stern will vary in the same proportion. For the

angle of the after adjusting water-line, so as to give the vessel a fine clean run, draw the line e' D', so as to form an angle of 30 degrees with the centre line of the floor-plane. Where this line cuts the after adjusting frame, it is the spot through which the adjusting water-line is to be drawn. With this degree of sharpness, the vessel will sail fair, and steer well.

Having shewn how to lay off the bottom of the vessel, and to give the proper degrees of sharpness to the run and entrance, the following Table shews the degrees of sharpness at the adjusting water-lines, *i. e.* the angles of the fore and after adjusting water-lines, proportioned in the manner we have now pointed out; the inward hollow of these water-lines between the after adjusting frame and the stern-post and the round outwards of the fore adjusting water-line, between the fore adjusting frame, and the stem; also the degrees of the rise of the midship-floor, from its base-line, of a number of merchant vessels, whose properties or characters are pointed out in the column of remarks. Their principal dimensions are given in the former table of general dimensions, (p. 147.)

A Table of the Sharpness and Angle of the Midship-Floors of Vessels.

Classes, and Ships' Names.	Tonnage.	After Body.		Fore Body.		Angle of the Midship-Floor.	REMARKS.
		Angle of the Water-Line.	Inward Hollow.	Angle of the Water-Line.	Round Outwards.		
	Tons.	Degrees.	Inches.	Degrees.	Inches.	Degrees.	
Sloops.—Ely Packet,	48	23	3	41	2	11½	*Plate* XIII. Built at Ely by Mr. Steel.
Bee, - - - -	53	31	3	42	3	9	
Margaret, - -	63	29½	4	48	2½	10	A good sea-boat, and sails fast.
Hope, - - -	70	45	2½	55	5½	5½	A bad sailer; did not steer well when loaded.
Thistle, - - -	85	25½	3	47	1½	10	A fast vessel.
Enterprise, -	130	27½	6	43	2	7	Sails fair. Kirkcaldy and London smack.
Elbe, - - -	140	25¾	4½	44	3	8½	Sails fair. Sails between Dundee and London.
Smacks.—Eagle, -	196	26	4½	45½	3½	7	Sails fair; very fast in light winds.
Edinburgh Castle,	190	24	5	48	2	8	A fine sea-boat, and sails fast.
Revenue Cutter, -	189	20	...	36	2	23¾	
Schooners.—William,	105	43½	9	55½	8½	6	A long bottom; very short, hollow run; carrried a great cargo, and sailed well.
Elizabeth, - -	113	37	5	55	6½	7½	A good sea-boat; sailed fair on the average, and very fast in a heavy sea, when blowing strong.
Glasgow, - -	155	29	5	47	3	9	Sails fair, and carries a great cargo.
Yacht, - - - -	218	18½	1	32	...	18	Meant for fast sailing, to be rigged either as a schooner or brig.
Brigs.—Blucher, -	158	33	4½	48	2½	9	A very fast vessel.
Amazon, - -	196	25½	3	43	2	10	Fast vessel upon a wind.

Table of the Sharpness and Angle of the Midship Floors of Vessels—(continued).

Classes, and Ships' Names.	Tonnage.	After Body.		Fore Body.		Angle of the Mid-ship-Floor.	REMARKS.
		Angle of the Water-Line.	Inward Hollow.	Angle of the Water-Line.	Round Outwards.		
	Tons.	Degrees.	Inches.	Degrees.	Inches.	Degrees.	
Brigs.—Mary, -	205	34	6½	50	1½	9½	Carries a very great cargo, and sails fast upon a wind. Answers very well.
Eudora, - -	263	33½	5	49½	3	8½	A remarkable fast vessel for burden.
Rambler, - -	296	39	3½	54	9	7	Not a very fast vessel. Carried a great cargo.
George, - - -	238	40½	4½	51½	7	6½	
William Young,	303	35	5	51	5½	8	Allowed to be a fast vessel.
Ships.—Arcturus,	370	34½	5½	51	4½	7	
Ditto, proposed at	400	32	6	48½	3½	7	See *Plate* XXIII.
Severn, - - -	567	35	6	47	1	10	Carried a great cargo; sailed fast.
Ditto, proposed at	500	32	5	45	3	8	See *Plate* XXIV.

The sheer and floor-planes being thus far completed, the main half-breadth line drawn, and the angles of the fore and after adjusting water-lines set off, the true station of the frames upon the keel must next be marked. Having determined upon the berth and space of the floors, take the width of four spaces in the compasses, and from the spot where you intend the foremost square frame to stand, (this is commonly at the fore adjusting frame), set these distances regularly along the keel till you come to ⊕ frame, (which may be shifted a little, so as to come in to the proper distance); then make the space at flat equal to five berths, and with the extent of four, as before, proceed till you come to the stern-post. To leave room for an additional timber in the middle of the ship, the berths and space at flat is made equal to five, to prevent two floors or two futtocks from coming together, as otherwise they would do, from the fore body floors being moulded on the after side, and the after body floors on the fore side.

As the scale by which the vessel is drawn is so small, compared to that on which she is built, a very small error in setting off the berth and space of the floors would be much augmented before you reached the stern-post; this makes a considerable difference in the true station of the after-frames; therefore it will be better to take a distance equal to the berth and space of 8, 10, or 12 floors in the compasses at once, and setting this along the keel, again subdivide them into the proper number; for although ¼ or ½ inch of difference in the divisions of the scale may not be perceptible, it will amount to some inches in setting off the berth and space of the floors on the ship. The aftermost square frame may be placed near the after adjusting frame in vessels of moderate sharpness, but for those that are very sharp, it is difficult to find floor-timbers with sufficient rise to form frames so far aft in the vessel; therefore in this case the after-frame must be placed a little farther forward than the after adjusting frame. When the station of all the floors is set off upon the keel, and it is intended that every other floor shall be a frame, which is

common, square them up through the sheer-plan, and down to the centre line of the floor-plane, and mark the distinguishing character on each, beginning at flatt, and marking those of the fore body ⊕ A B C, &c.; or, if the immediate floors are left out, thus—⊕ B D F, &c.; mark thsoe of the after body, beginning at flat, 1, 2, 3, 4, &c.; or, missing the intermediate floors, 2, 4, 6, 8, &c.

On the Body-Plan, or Plan of Projection, and the Construction of the Midship-Frame.

The plan of projection represents the form of the vessel when cut at different parts of her length by vertical transverse sections, the largest of which is called the midship-section, or more commonly the midship-frame, in reference to the frames that are made to these sections. This being the largest, all the other sections or frames may be inscribed within it; so that in the plan of projection may be exhibited all the square thwartship timbers, supposing the view either from the bow or stern. In this plan the timbers appear with their proper curvature, either convex, concave, or both, according to the place and position of their cutting planes. The ribband-lines in this plan will appear straight lines, as they merely represent the cutting planes of the ribband-lines; also, the water and buttock-lines appear straight lines in the plan of projection. The body-plan may be placed at the stern-end of the vessel, on a line with the upper edge of the knee, which will form the base-line, or at any other convenient part of the paper. Draw a straight line for the base-line, in the middle of which erect a perpendicular for the centre line of the body-plan; on each side of which, mark on the base-line the half breadth of the midship-frame. At these spots, square up lines parallel to the centre line, and these will be tangents to the midship-frame at the sides. Also, on each side of the centre line, mark the half thickness of the stem and stern-post, and at these spots square up lines parallel to the centre line; likewise draw a section of the keel immediately under the base-line.

The length and rising of the midship-floor is next to be found. There is not any correct rule for the length and rising of the midship-floor; but by referring to the 8th column of the last table, the reader will see the angle of the rise of the midship-floor of a great number of vessels, all of which take the ground with safety, with the exception of the cutter.

In general, the length of the midship-floor may be made 3-5ths or 2-3ds of the breadth of the midship-frame, (2-3ds is considered rather broad), and have a rising of about one-half or 3-4ths of an inch for every foot of its length, or one inch for every foot of length from the keel outwards to the floor-ribband or sir-mark. Having found the length of the midship-floor, measure its half length on the base-line on each side of the centre line of the body-plan; at that spot square up a short line, and on it set up the intended rising of the midship-floor, then from that spot draw the floor into the keel at the upper edge of the rabbet. The floor should be straight, or have a small inward hollow as it nears the keel.

The floor being drawn in, determine upon the lower height of main-breadth, that is, the spot on the tangent-lines where the curve of the midship-frame joins the upright

part of the side; this spot will be higher up or lower down, according as you intend the vessel to have a sharp or full midship-frame, but is commonly at half the height of the midship-frame. The best way to trace the bilge part of the midship-frame is by means of intersecting lines, drawn in this manner (*See Plate* XII. *Fig.* 3)—Continue the straight line of the floor out to meet the vertical line of the side, and divide it, between the floor-head and vertical line of the side, into any convenient number of equal parts; also divide that part of the vertical line of the side, contained between the lower height of breadth and where the line of the floor cuts it, into the same number of equal parts; mark the divisions 1, 2, 3, &c.; also mark those on the line of the floor from the side line 1′, 2′, 3′, 4′, &c.; then join 1 1′, 2 2′, 3 3′, and their intersections will be spots through which to draw, with a proper mould, the round or bilge part of the midship-frame. This being done, next draw in the top part of the frame, according to the intended tumble-home which you mean the top-side to have.

Proceed to draw in the diagonals in the body-plan, according to the following rules for each, (*See Plate* XII. *Fig.* 3.) It is a point of importance to place these lines in their proper position, for it is evident that if they are placed low and flat, the lines in the floor-plane will become flat in the middle and towards the stem and stern-post, while at the same time they will be very full, and suddenly round on the quarters. Under such circumstances, it is difficult to judge whether the vessel is properly constructed or not; that is to say, whether the ribband-lines are of the proper form.

The heights of the diagonals on the centre-line may be found thus:—Take 5-8ths of the breadth of the midship-frame, and set it up on the centre-line (*Fig.* 3); divide the distance between it and the base-line into four equal parts; the first from the base-line will be the height of the first diagonal or floor-guide; the second division will be the height of the second diagonal or floor-ribband, also the floor rising-line; the third division will be the height of the third diagonal; and the fourth will be the height of the fourth diagonal on the centre-line.

Having the heights of the diagonals on the centre-line, the second diagonal is first drawn in. Its place on the base-line will be about 1-7th of the breadth of the midship-frame from the side-lines, or 5-7ths of the half breadth from the centre; it should stand with an angle of 42 or 42½ degrees from the base-line, as shewn by the figure. The first diagonal or floor-guide should be drawn parallel to it; the third diagonal should be drawn from a spot on the side-lines equal to 1-8th of the breadth of the frame up from the base-line; and to find the spot on the side-lines from which to draw the fourth diagonal, take half the length of the midship-floor in the compass as a radius, and with the point *g′* as a centre (that is, the floor-head), sweep round an arc cutting the side-lines, and that will be a spot in the side-lines from which to draw the fourth diagonal.

These are the principal diagonals, but sometimes a fifth one is laid down for the purpose of forming the buttock in large vessels, and it should be placed parallel to the fourth diagonal, at about half the distance from it that the fourth is from the third. It will also run nearly parallel to the lower edge of the wales in the quarters of the ship. If the diagonals are placed according to the above rules, they will be found very convenient in draughting any vessel of the British construction.

In extending the plan to the floor of the moulding-loft, other diagonals are struck in, at the discretion of the foreman, in order to correct the work, and obtain all the necessary bevellings, and to point out the heads of the different timbers, according to the proper shiftings, or, as may be thought most convenient, for carrying on the work according to the nature of the material with which the vessel is to be built.

Having the diagonals drawn on the body-plan, next draw in the water-lines. The water-lines and transoms are commonly drawn first on the sheer-plan, and transferred to the body-plan; when this is done, the next thing is to draw the balance and adjusting frames in the body-plan.

For the balance-frames, take their main half-breadth from the floor-plane, and transfer it to the body-plan. On the sheer-plan, set up the height *h* P, according to the round intended on the rising line between the balance-frames, as before noticed; set the same up from the base-line of the body-plan, to where it meets the second diagonal; from that point, draw the floor part of the frame inwards to the side of the keel, (in order to avoid confusion, we have left out these frames in *Fig.* 3); then proceed to draw the round or bilge part in the same manner as the midship-frame. Next draw in the adjusting frames in the body-plan: to draw the one in the fore body first, dot a line across the right side of the centre-line, parallel to the base-line, and at the exact height above it that the fore adjusting water-line is above the upper edge of the keel in the sheer-plan. Proceed to the floor-plane, and take the distance *r s* (that is, the breadth of the adjusting frame at the adjusting water-line); set this on the adjusting water-line in the body-plan, as *r′ s′*; also proceed to the sheer-plan, and take the upper and lower height of breadth of the frame, and mark it on the body-plan. From the floor-plane, take the main half-breadth at the adjusting frame, and transfer it to the body-plan; then, through these points, dot lightly with the pencil the adjusting frame, and after you have got it to please, proceed and measure off the after adjusting frame.

Although the run of the vessel is to be formed by the adjusting frame in the same manner as the entrance, yet there is a little more difficulty in forming this frame so as to give the intended degree of sharpness below, and at the same time preserve a sufficient round on the buttock, according to the sharpness of the bottom and proposed depth to which the vessel is to be loaded. Upon the due proportioning of this part of the vessel, many of her good or bad properties chiefly depend. Thus, if she is too thin on the quarters, there is not only a loss of stowage, but when the ship is going against a head-sea, she will fall too much down aft, which not only retards the sailing, but also makes the vessel dangerous in scudding, and a bad roader when at anchor.—On the other hand, if the buttock is too low, the ship will both sail heavily and steer badly when loaded, and also be often in danger of broaching-to when scudding before the sea in heavy gales. Therefore it requires great attention, even with those who have had considerable practice, to form a proper buttock.

Owing to the various dimensions of length, breadth, and height, breadth abaft, sharp or fully, as may be required, it is perhaps impossible to give any invariable rule that will answer every description of vessels. However, I shall point out a method of draw-

ing the buttock and quarter, by first forming the adjusting frame by a rule, which I think is pretty correct, and will produce a very suitable buttock and quarter for all sea-going merchant vessels.

Having the height of the adjusting water-line drawn across the after body-plan, take its height from the base-line; set this distance above the adjusting water-line, and square it across, also parallel to the base-line. In most cases, it will be the lower height of the main-breadth at the after adjusting frame; it is also the greatest height at which the wing-transom should be placed. Next, above this line set half the height of the adjusting water-line, and draw it across; we shall then have three lines across the body, parallel to the base-line. Take the width of the adjusting frame at the adjusting water-line (according to the degree of the angle of the adjusting water-line), and set it from the centre-line of the body-plan on the adjusting water-line, which will be a point through which the adjusting frame must pass; then take the main-breadth of the adjusting frame off from its place in the floor-plane, and set this on the lower height of breadth line in the body-plan, *i. e.* the line at twice the height of the adjusting water-line from the base-line; then draw a straight line from the spot on the adjusting water-line, where the adjusting frame is to pass, to the main-breadth, as marked on the lower height of breadth line, and this inclined line will give the sloping-out of the quarter. (Also shewn by *Fig.* 121, *Plate* VI.) Next, from the main-breadth draw a line upwards, perpendicular to the sloping line of the quarter, and it will cut the line drawn at half the height of the adjusting water-line above the lower height of breadth line (or line of the wing-transom), and from the intersection of these lines to the main-breadth spot, is the length of a radius to sweep the round of the quarter of the adjusting frame. To do this, take that radius in the compasses, place one foot on the lower height of breadth line, at such a distance in or out that the other point or leg will touch the main-breadth; then sweep the round of the adjusting frame; next, from the back of the circle, draw, with a round-ended mould, a fair curve, passing down through the breadth mark on the adjusting water-line to the inside of the rabbet of the keel. If the curves are corresponding, the inward hollow below the adjusting water-line will be about 2-3ds of the outward round between the adjusting water-line and the transom or lower height of breadth.

To draw the Rising-line in the Sheer-plan.

From the plan of projection (*Fig.* 3) take the rise of the midship-floor $g\,g'$ from the base-line, and set this height from the upper edge of the keel on the flat-frame marked ⊕; take the additional rising of the balance-frames above the flat-frame, so as to allow a proper round of the bottom, as before observed, and set it on the balance-frames; next take the vertical height, where the adjusting frames in the body-plan cut the second diagonal, *i. e.* the height of the intersection of the second diagonal by the adjusting frames above the base-line; set this on the respective adjusting frames in the sheer-plan, and you will then have five spots through which the rising-line is to be drawn, *i. e.* a spot on the fore adjusting frame, one on the fore balance-frame, at flat-frame, at the after balance-frame, and on the after adjusting frame. But the rising-line cannot be

drawn until we have found the spot at which it will terminate on the stem and stern-post. Measure from the base-line of the body-plan, up the line which represents the half thickness of the stem or stern-posts, to where it is intersected by the second diagonal; set this height up from the upper edge of the keel, to where it cuts the stem and stern-posts in the sheer-plan, at which spot square a level line, crossing the rabbet of the stem and stern-posts, and it will be the ending of the rising-line at the same. With proper moulds, or a thin bottom which will bend fair, draw the rising-line from stem to stern-post, *i. e.* the line marked *Rising-line of the floors;* (these lines supposed to be drawn are only pencil lines, as they may perhaps require some small alteration.) The straight lines, such as the upper and lower edge of the keel, the base and perpendicular lines of the body-plan, and the proper frames in the sheer and floor-plans, the centre-line, &c. may now be drawn with ink.

The rising-line is the first longitudinal line used for forming the bottom, and its height above the keel at any place is the rising of the floor at the same. The rising-line represented on the plate is different from that used in whole-moulding, in which it only gives the height of the bilge sweep, and not the rising and length of the floors, as is the case here.

The next line to be drawn is the lower height of breadth, which marks the place on the frames where they begin to round inwards to form the bottom. Find the spot or flat-frame through which this line is to pass, by measuring from the base-line up the side of the body-plan, to where the midship-frame touches the tangent-line; and setting this height on flat-frame in the sheer-plan, take a mould and draw the lower height of breadth line, passing through that spot, and running nearly parallel to the rising-line from stem to stern. Next draw the upper height of main-breadth line (this is commonly made a dotted line) from stem to stern, parallel to the main-sheer line, and about 8-9ths of the height of the vessel from the keel (*see Fig.* 1.) The timbers above the upper height of breadth line incline inwards, for the purpose of making the stanchions and rail clear the shrouds. The side of the vessel, between the lower and upper height of breadth, is commonly straight and perpendicular, except at the bow, where the timbers incline outwards. The lower height of breadth line is seldom used at that part of the vessel, the bow being formed and faired by the harpins.

In drawing the upper height of breadth line, it must be continued beyond the stem as far as the curve of the main-breadth line in the floor-plane would extend when continued out straight; for it must be observed that the lines which represent the harpins in the sheer-plan are not the full length of these lines in the floor-plane. Therefore, if we do not raise the sheer of the vessel a little at the bow, she will appear to drop down forward from the regular main-sheer. In order to allow for the loss of curvature which takes place by the sheer-lines going round the bow, it is necessary to raise these lines a little higher at the stem than the fair sheer. In general, the main-breadth line, where it goes round the bow, as shewn in the floor-plane (*Fig.* 2), will extend, when continued straight out, 1-5th of the ship's breadth beyond the rabbet of the stem at the height of that line. Therefore, if upon the sheer of the main-breadth lines continued beyond the stem in the sheer-plan, we mark 1-5th of the ship's breadth before the rabbet at that

line, and then mark the height of the sheer-line at that distance before the stem, upon the inside of the rabbet, it will be the height to which the regular sheer should be raised gradually from about the fore balance-frame. Having found a ribband-line mould which will raise the sheer to the height at the stem, and reconcile well with the sheer abaft the fore balance-frame, mark the place of the mould at the stem, and proceed to raise all the sheer-lines with the same mould, observing to keep the mark on the mould at the rabbet of the stem. This rising of the sheer from the fair circular curve is not intended to be apparent when the vessel is built, but is only an allowance for the curvature of the round of the bow. To be more correct than is directed above, these lines should only be drawn with pencil, until such time as all the harpins are run in the floor-plane, when the rounding-in of each may then be correctly measured, and the neat additional rise of each found and drawn on the sheer-plan. The reader will observe, that the main-breadth harpin, from the fore adjusting frame to the stem (*see Fig.* 2) is measured off by 15 divisions; that they are set off on the extension of the upper height of main-breadth line, and the height of the same at the 15th division squared in to the rabbet of the stem (*see Fig.* 1), which gives the point to which the sheer-line must be raised.

To transfer the Rising of the Floors from the Rising-line to the second Diagonal in the Body-plan.

When the rising-line is drawn in the sheer-plan, measure its height above the upper edge of the keel at each of the intended frames; and transfer these heights from the base-line of the body-plan, to intersect the second diagonal (keeping the compass points vertical to each other.) Having the rising of the floors of the different frames marked on the second diagonal, draw with a straight batten the floors from each of these spots to the rabbet of the keel, with the exception of a few near the stern-post, which must gradually partake of more and more inward hollow as they near the stern. On all the floors of the frames thus drawn, mark the distinguishing name or character of the frames from which they were taken in the sheer-plan.

When it is intended to draw the rounding part of the bottom by sweeps of the compasses, its correctness will depend entirely on the accuracy with which the lower height of breadth and radius lines are drawn to their proper place, and perfectly fair. The floor-head diagonal ribband-line is commonly placed a little higher in the centre, to about 44 degrees of elevation from the base-line; and the lower height of breadth line is drawn as nearly parallel to it as possible, which may always be done to a little before and abaft the balance-frames, through which and the adjusting frames on the bow and quarter, at their lower height of breadth, it must pass. The next thing is to draw a line in the floor-plane, to represent the length of the radius for the main-breadth sweep of the frames. Take the length of the radius, by which the round part of the foremost and aftermost adjusting frames, and also the midship and balance frames, are swept; set off their distances from the middle line of the floor-plane on their respective frame-lines, which will be spots through which the radius-line must be drawn; but in the event of those spots not being so situated that a fair line will pass over them, they must

be altered a little, in or out, so as to produce a regular fair curve. When the lower height of breadth and radius lines are thus adjusted, proceed to sweep all the square frames of the side from the lower height of breadth downwards. Take from the sheer-plan the lower height of breadth, and set up from the base-line of the body-plan; draw a line across at that height from the main half-breadth line in the floor-plane; take the half breadth of the intended frame, and set it from the middle line in the body-plan on the proper height of breadth line; take from the middle line of the floor-plane the width of the radius-line of the respective frame in the compasses, and with one foot set in the lower height of breadth line in the body-plan, and the other at the main-breadth, as marked on it, describe an arc downward, which will be the rounding of the frame downwards from the lower height of breadth to the head of the first futtock in high built vessels, and to the floor-head in low flat vessels. In high vessels, as shewn by *Plate* XII. *Figs.* 3 and 4, the main-breadth sweep, if continued, will come outside of the floor-head. In this case, a second sweep is required, which is commonly called the reconciling sweep; to find the centre of which, draw a line at right angles from the sir-mark of the floor, or the part of the straight you intend the curve to diverge from; then take such an extent in the compasses as will reach from any spot on that line to the nearest part of the main-breadth curve, and it will be the centre of the reconciling sweep. A line drawn from the centre of the main-breadth sweep, through the centre of the reconciling sweep, will cut the main-breadth sweep at the place where the reconciling sweep must come to.

When as far forward or aft as half way between the balance and adjusting frames, one sweep will commonly answer the purpose; and with vessels of a low flat construction, one sweep may, as taken from the radius-line, nearly answer the whole frames of the side, which is the next step to that of whole-moulding.

The centres of the main-breadth and reconciling sweeps are distinctly marked on *Fig.* 4, *Plate* XII. For example, let us sweep frame B. The rise of the floor *p* P is taken from the sheer-plan, and set up from the base-line of the body-plan on the second diagonal, as *h*, and the floor drawn straight to the keel. The lower height of breadth is taken from the sheer-plan, and set up from the base-line of the body-plan. The main-breadth of the frame is taken from the floor-plane, and set from the centre line of the body-plan, on the line squared across at the lower height of breadth, and the upright part of the frame squared up. Next take, from the centre-line of the floor-plane, the radius of frame B; set this in from the main-breadth of the frame on the lower height of breadth line, and you will have the centre *b* at the end of the line marked *Rad. of frame B*. Then sweep the frame down to *b′*, from which draw the dotted line to the centre *b*, i.e. the line *b′ i b*; then, from the floor-head draw up a line at right angles, as *h i*, cutting the line *b′ b* in *i*, which is the centre of the reconciling sweep, with which sweep from *b* to *h*, and frame B will be completed to the upper height of breadth. All the others being swept in the same manner, the diagonal ribband-line, as formed by the rise of the floors, may now be taken from the body-plan, and transferred to the floor-plane.

To find the termination of the ribband-line, let fall vertical lines from the spot where

the rising-line ends, at the inside and outside of the hoods or rabbet of the stem and stern-posts in the sheer-plan, down to the centre-line of the floor-plane. Then take the diagonal half-thickness of the stem and stern-post, and set it from the centre line of the floor-plane on the line of the outside of the rabbet of the stem and stern-post, as squared down from the sheer-plan. From that point as a centre, sweep inwards the diagonal thickness of the bottom plank, at the back of which the ribband-line must be brought in, so as to form a tangent to the inside of this small circle. To find the points on the frames through which the ribband-line is to be drawn, begin with the fore frame, and measure from the centre-line of the body-plan, down in the direction of the diagonal, to the rising of the fore frame; set this off from the centre-line of the body-plan on the fore frame in the same. In this manner, transfer all the other floors to the floor-plane, and through these spots draw the diagonal ribband in the floor-plane.

But as some of these spots may be too far in or out to make the ribband-line a fair curve, the rising of the floors must be altered a little, so that, when measured to the floor-plane, the ribband-line will be fair. In drawing this, observe that the rising of the floors may not correspond with the rising-line in the sheer-plan; therefore it must be altered a little, to correspond with the alteration made upon the rise of the floors in the body-plan; but no alteration must be made on the rising at the adjusting and balance-frames, otherwise the balancing of the bottom of the vessel will be destroyed. If the spots on the frames in the floor-plane make a fair ribband-line at the first, it is a proof that the rising-line in the sheer-plan has been drawn correctly, which however is seldom drawn correctly at first, but may sometimes happen. If the rising-line and the ribband-line in the floor-plane run quite fair, having no sudden rounds or flats in them, proceed next to draw the other ribband-lines in the floor-plane, beginning with the third diagonal ribband. The termination of the third ribband-line is found in the same manner as directed to find the ending of the second ribband, *i. e.* by taking the height where the diagonal cuts the side-line of the stem and stern-post in the body-plan; setting this height perpendicularly up from the upper edge of the keel, to the stem and stern-post in the sheer-plan, and then squaring it down to the centre-line of the floor-plane, on the line at the outside, set the diagonal half-thickness of the stem, and then sweeping in the diagonal thickness of the plan, gives the ending of the ribband.

Having in this manner found the proper place at which to bring in the ending of the ribband, measure from the centre-line of the floor-plane, down the third diagonal to the fore adjusting frame; set this distance from the centre-line of the floor-plane on the adjusting frame; measure down the diagonal to the fore balance-frame; set this on the same in the floor-plane; also measure down the diagonal to ⊕ frame, and set this ⊕ frame in the floor-plane; also measure off the after adjusting and balance-frame, and all the other frames or timbers drawn on the body-plan; mark them on their respective frames in the floor-plane; then through all these spots draw the ribband-line in the floor-plane. The fourth and fifth ribband-lines are drawn in the same manner.

Having the diagonal ribbands, the main half-breadth, and part of the adjusting water-lines, drawn in the floor-plane, next run the top half-breadth line, which owing to the

tumble-home of the top-sides, will be within the main half-breadth line, except at the bow, where it extends without the main half-breadth line, as marked *u* in the floor-plane, *Plate* XIII. for giving a fine flange or cast-out to the bow. By inspecting any of the plans, as *Plate* XIII., it will be observed, that the top-breadth line runs nearly parallel to the main-breadth line from the stern to about frame ⊕, passing which as it goes forward, it nears the main-breadth line, and at last intersects it at about the distance of 2-3ds of the ship's breadth from the stem. The termination of the top-breadth line at the stem is found by squaring down the spot where the top-height line in the sheer-plan cuts the inside of the rabbet of the stem. The top-height line shews the heights of the frames; while the top-breadth line in the floor-plan shews the top half-breadth of the frames.

The top-breadth line being drawn, square down to the centre-line of the floor-plane, the exact spot where the lower edge of the main-wales cuts the inside of the rabbet of the stem, and that will be the spot where the harpin or lower-wale will end on the side of the stem in the floor-plane. Take an elliptical mould, which is a small thing, flatter in the curve than the one which drew the fore or bow part of the main half-breadth line; lay the fore end of the mould at the spot on the stem, and make the other end to coincide with the main half-breadth line, exactly below where the lower height of breadth line cuts the under edge of the main-wales in the sheer-plan. Having the mould thus placed, draw round, from where it touches the main half-breadth line, to the stem, and you will then have three principal harpins drawn, *i. e.* the bend-harpin commonly called the lower harpin—the main harpin, or the round part of the main-breadth line, from the fore balance-frame to the side-line of the stem—and the top-harpin, or the continuation of the top-breadth line round to the stem. Having these lines run in the floor-plane, proceed to draw in or correct all the frames on the body-plan, supposing that they have already been drawn in by sweeps of the compasses, as before directed. But if they are to be drawn with the small moulds, take the lower height of breadth of the frame immediately next to ⊕, either before or abaft it; set this height on the side-line of the body-plan, on the same side as the frames are to be drawn; take also the upper height of main-breadth, and the top-height, and set these on the same side-line; square them across towards the centre of the body plan; from the floor-plane take the main half-breadth of the frame, and set it from the centre-line of the body-plan on the lower height of breadth; square up this to the upper height of breadth; next take the top-breadth of the frame from the floor-plan, and set it on from the centre-line of the body on the top-height line; draw the tumble-home part of the top-timber. Take the breadth of all the ribband-lines on the frame from the floor-plane, and set them down from the centre-line of the body-plan on their respective diagonals, and then through these spots draw the curving part of the frame. If it is found that the curve of the frame, after passing through these spots on the diagonals, is not quite fair, you must examine the curve of the ribband-line at that frame on the floor-plane, and observe where any small alteration can be made on them, so as to bring the timber or frame fair in the body-plan.

In the same manner proceed to prick off all the other frames, both in the fore and

after bodies. Observe, when you come to draw the frames, before the spot at which the lower height of breadth line cuts the lower edge of the wales in the sheer-plan, take the height of the lower edge of the bends or wales from the sheer-plan, and set it on the body-plan, and draw a level line across the frames; on this set the breadth of the vessel at the lower harpin taken from the floor-plane; should it be found that this breadth is not correct, so as to coincide with the fair curve of the frame in the body-plan, alter the lower harpin a little, so as to bring them to agree.

After the frames are all drawn on the body-plan, as some of the other pencil lines will be nearly rubbed out, a few of them may now be drawn in with ink; but observe not to ink in the frames in the body-plan, nor the ribband-lines in the floor-plane, because these may perhaps require to be altered a little, so as to make fair water-lines and buttock-lines.

On the Water-Lines.—We have before observed that there are two positions of the plane of the water-lines on the sheer-plan, *i. e.* the level, or those parallel to the keel, and the other inclined to the keel, as when the vessel is intended to float by the stern. Suppose the vessel is intended to float 2 feet by the stern, and it is desired to represent the water-lines as they would really appear on the vessel when launched; then, as the keel is commonly drawn level on the plan, the plane of the water-lines in the sheer-plan must be made 2 inches off the level, higher abaft. When the water-lines are drawn off the level in the sheer-plan, they will not be straight lines in the body-plan, but form a particular curve, sloping up towards the stern-post on the after body, and from the midship-frame sloping down as they approach the stem on the fore body. Now the water-lines, when drawn level in the sheer-plan, are also level, and represented by straight lines on the body-plan. As they are the most easily understood, I shall first notice the method of running the level water-lines, and of correcting the frames. Supposing them not to be run on the sheer-plan, continue the fore adjusting water-line on the sheer-plan right aft to the stern-post; also continue the after adjusting water-line right forward to the stem; then draw the water-lines across the body-plan parallel to the base-line, and be very particular in making them the same height above the base-line that they are above the upper edge of the keel in the sheer-plan. Square down the spot where these water-lines cut the outside of the rabbet of the stem and stern-post, to the line which represents the half-thickness of the stem and stern-posts on the floor-plane; then take the thickness of the plank in the compasses, and set one point on the fore side of the rabbet at the side of the stem and stern-posts, and describe a small arc inwards, and that will be the true ending of the water-lines in the floor-plane. On the body-plan, measure the distance from the centre-line to the foremost frame, where it is intersected by the water-line; transfer this from the centre-line of the floor-plane on its respective frame. Proceed to the body-plan again, and take the breadth of the next frame on the same water-line; set this on its respective frame in the floor-plane, and so on, measuring the breadth of all the frames on the water-line, and setting them on their respective frames in the floor-plane, until you come to the aftermost frame; then through all these spots draw the water-line in the floor-plane. In the same manner proceed with all the others.

If any of the frames be too full, or too lean, so as to make the water-lines unfair, alter them in the body-plan (but take care not to alter the frame so as to make the ribband-lines unfair), by taking one frame in and another out a very little, and altering the ribband-lines at the same time to correspond, if the ribband-lines are affected by any small alteration which you may have made on the frame in order to get the water-line fair. Perhaps it may require a considerable altering in this way before you bring the curve of the frames in the body-plan, and the ribband and water-lines in the floor-plane, all quite fair and correct to the measurement, as must be the case if it is intended to have a correct plan.

The frames being made quite fair, and to make fair the ribband and water-lines in the floor-plane, we may conclude that the bottom, so far as it has thus been proved, is correctly formed; at the same time, it must be proved farther by running the buttock-lines, before which run a water-line, supposing the vessel to draw 2 feet more water abaft than forward. Accordingly, draw the load-water line 2 feet higher aft than forward; square down where it cuts the rabbet of the stem and stern-post, and find the ending of the water-line in the floor-plane, as before; measure the height of the water-line above the upper edge of the keel at the stern-post; set this up from the base-line of the body-plan on the side-line, which represents the half-thickness of the stern-post; take the height of the water-line on the aftermost frame in the sheer-plan; set this perpendicularly up from the base-line of the body-plan till it cut the aftermost frame in the same; make a mark at that spot on the frame; take the height of the water-line at the next frame in the sheer-plan, and set it on its respective frame in the body-plan, and so on with every frame in both the fore and after body; through all these spots draw the water-line across the frames, as done in the brig of 223 tons, *Plate* XIX; then proceed to measure it off from the body-plan to the floor-plane, in the same manner as any other water-line, *i. e.* by measuring from the centre-line of the body-plan, square across to where the water-line intersects the different frames, and then setting these distances from the centre-line of the floor-plan on their respective frames, and drawing the water-line, passing through all the spots or marks on the frames.

To draw the Buttock-lines.—These are used for forming the buttock and after run; also for pricking off the mould of the transoms, and for finding their proper bevel. The buttock-lines must be first drawn on the body-plan; the distance between them is commonly about 18 inches. Take this distance in the compasses, and turn them over on the base-line from the centre-line four or five times, according to the number of buttock-lines you intend to have, and at each of these square up lines perpendicular to the base-line; mark the same distances from the centre-line of the floor-plane on the perpendicular line let fall from the seat of the wing-transom, and at each of these draw lines along the floor-plane parallel to the centre-line, for the plane of the buttock-lines.

In pricking off the buttock-lines, it will be necessary to measure with the greatest exactness; for as these lines cross the frames obliquely, a very little variation of the point of the compasses from the line will cause an error of an inch or two, which will make the lines to run unfair in the sheer-plan; therefore, in pricking them off,

observe to place the point of the compasses exactly on the buttock-line. Allowing the measurements to be taken to a nicety, yet the frames in the body plan may require some trifling alteration before the buttock-lines will be fair on the sheer-plan. In making this alteration, observe to alter the adjusting frames as little as possible. To prick off the buttock-lines, begin first with the one next the centre of the ship, which is commonly marked 1*st B. L.*; from the base-line take the height of the aftermost frame or timber, where it is cut by the buttock-line; set this up from the upper edge of the keel on its respective frame in the sheer-plan; then from the base-line take the height of the next frame at the same buttock-line, and set it on its respective frame in the sheer-plan, and so on with every frame for as far forward as you intend to run the buttock-line in the sheer-plan. Then through all these spots draw the buttock-lines running up to the counter; they are commonly dotted lines, to distinguish them from the other lines that are drawn in the sheer and floor-plans. After one buttock-line is drawn, all the others are run in the same manner, making what little alteration may be required on the frames in the body-plan, in order that the buttock-lines may run quite fair in the sheer-plan. After thus altering and correcting the frames by the ribband, water, and buttock-lines, it might be supposed that they are now correct; but of this we cannot be certain until we have laid down the transoms and fashion-timbers.

On the Transoms.

The transoms have two positions of their plane—the one parallel to the keel, and the other canted up at the fore end. The first are called level transoms, and the second cant transoms. Commencing with the level transoms first: Suppose we have the upper side of the wing-transom drawn according to the proper height, which has been pointed out, p. 179, take the berth and space of the transoms (which is commonly the same as the berth and space of the floors) in the compasses, and turn them over from the wing-transom on the perpendicular line let fall at the seat of the wing transom, at the inside of the rabbet of the post, and at each of these spots draw forward lines parallel to the keel, and they will represent the planes of the different transoms, *i. e.* their upper sides, which is commonly called the moulding-edges, as the transoms are commonly moulded on this side. When they are placed on the post, the next thing is to to transfer the plane of the transoms to the body-plan. Measure their height above the upper edge of the keel in the sheer-plan; mark these up from the base-line of the body-plan, and at each of the marks square a line across the after body frames parallel to the base-line. These will cross the frame the same as water-lines, and may be measured off from the body-plan, and transferred to the floor-plane in the same manner; also their termination is found in the same manner as a water-line. In place of measuring off the transoms from the frames in the body-plan, they are commonly pricked off from the buttock-lines in the sheer-plan. Sometimes the wing-transom is drawn on the floor-plane before the buttock-lines are run, but then it must only be drawn with the pencil, as it may require to be altered, to correspond with the buttock-lines. The extreme breadth of the wing-transom, where it is cut by the fashion-tim-

ber, is commonly about 9-10ths of the main-breadth at the wing-transom, and its fly forward at the ends, before the perpendicular line, about 1-6th of the half main-breadth of the transom; but the breadth of the transom will be varied according to the round given to the quarters at the buttock, and according as it is placed higher up or lower down on the stern-post.

After the seats of the transoms are squared down to the floor-plane, take the compasses, and measure from the seat of the wing-transom to where it is cut by the first buttock-line; set this distance from the perpendicular line (which is squared down from the seat of the wing-transom), on the first buttock-line in the floor-plane; take the distance where the transom in the sheer-plan is cut by the second buttock-line, and set this from the perpendicular on the second buttock-line in the floor-plane. In the same manner, take the intersection of all the buttock-lines with the wing-transom, and transfer them to their respective buttock-lines in the floor-plane; measure off the breadth of the after frames, at the level of the wing-transom on the body-plan, and set them on their respective frames in the floor-plane; then through these spots and the spots on the buttock-lines, draw the curve of the transom; you will then have a water-line in the floor-plane, cutting the vessel at the height of the wing-transom. Next draw the cutting-plane of the transom-ends, *i. e.* the fashion-timber line (marked *o o'*, *Plate* XIII.), so as to form an angle of about 70 degrees with the centre-line of the floor-plane. The cutting-line of the transoms is drawn from where the perpendicular line let fall from the seat of the wing-transom intersects the tangent-line of the side in the floor-plane; and that part of the water-line which has now been drawn, from where it is cut by the fashion-timber, round to the centre-line, is made the wing-transom.

When the wing-transom is drawn, proceed and prick off the others in the same manner, only observing to draw them properly into the rabbet of the post, to allow for the thickness of the plank, which will be greater as the lower transoms are sharper, as will be seen distinctly by inspecting the transoms in the floor-plane of the 400 ton ship (*Plate* XXIII.), when the transoms are all drawn in the floor-plane. Next draw the fashion-timber in the body-plan; measure from the centre-line of the floor-plane, along the fashion-timber line, to where it is cut by the lower transom; set this distance from the centre-line of the body-plan on the lower transom; then measure from the centre-line of the floor-plane, along the fashion-timber, to where it is cut by the next lower transom, and set it on its respective transom in the body-plan; and in the same manner, prick off all the transoms, where they cut the fashion-timber in the floor-plane; transfer the distances from the centre-line of the body-plan upon their respective transoms; then through all these spots draw the fashion-timber in the body-plan.

In pricking off the transoms from the buttock-line, it may be required to alter some of the buttock-lines a little to get the transoms to run fair; this, again, will cause you to alter the frames in the body-plan; also the ribband-lines in the floor-plane must be altered, to correspond with the frames. Sometimes the smallest alteration on the frames, or on any particular frame which may be lean or full on the buttock-line, will be sufficient, as the breadth of a line farther out or in upon the frame will make a considerable difference upon the buttock-lines, as they cross the frames obliquely.

On the Cant-Transoms.

Having shewn the method of pricking off the level transoms and fashion-timber, as used in the plan of the packet (*Plate* XIII.), we shall notice the cant-transoms, which have their planes canted up about 3 inches to the foot, or nearly square of the inside of the stern-post, when it has a rake aft of 3 inches to the foot. The object in canting the plane of the transoms upwards, is to assist the conversion of the materials, as the timber will not require to be so much bevelled off as when the transoms are laid level. The cant-transoms are measured from the perpendicular line let fall from the seat of the wing-transom, and transferred from the same to their respective buttock-lines in the floor-plane, in the same manner as the level transoms, but must not be squared down, for the plane of the transoms being canted up at the fore end, if the spots where they are intersected by the buttock-line are squared down to the floor-plane, it will only give the sine of the angles of the plane of the transoms, in place of the true length.

When all the transoms are pricked off from the buttock-lines in the sheer-plan to the floor-plane, and finding that they go fair, draw in the cutting-plane of the fashion-timber to the proper angle. Square up a pencil line, from where it cuts the centre-line, to the wing-transom in the sheer-plan; then draw, from the seat of the wing-transom, a line parallel to the keel. Take the compasses, place one point in the seat of the wing-transom, extend the other point to where it is cut by the vertical line which has been drawn from where the fashion-timber cuts the centre-line of the floor-plane; sweep this down to the level line drawn from the seat of the transom; square this point down to the centre-line of the floor-plane, and from it draw a straight line to meet the tangent-line of the side, and you will then have the cutting line of the transom-ends when they are transferred from the canting up to the level plane. It is this last drawn line which is taken for the fashion-timber. Sometimes there will be very little difference between these two lines, according as the plane of the transoms is canted up. I have left both of these lines in some of the plans, to assist the reader by a reference to them. The after line represents the situation of the fashion-timber when the transoms are up, as in the sheer-plan; the fore line, the fashion-timber, or cutting line of the transom-ends, when they are laid level, as on the floor-plane.

To draw the plane of the cant-transoms and fashion-timber on the body-plan, is the next operation, and is performed thus:—Take the distance from the centre-line of the floor-plane, measured along the after cutting plane of the fashion-timber, to where it meets the perpendicular line let fall from the seat of the wing-transom; then on the base-line of the body-plan (continued beyond the main-breadth), set this distance from the centre-line, and square up a line perpendicular to the base-line, or parallel to the tangent-line of the side—(*See the body-plans of the* 300 *and* 400 *ton ships, Plate* XXII. and XXIII.) Set up, from the base-line on the vertical line, the height of the plane of the transoms, taken from where they meet the perpendicular line let fall from the seat of the wing-transom in the sheer-plan; also measure the height of the plane of the transoms on the after perpendicular line squared up from the cutting plane of the fashion-timber, and set these up from the base-line of the body-plan on the centre-line; then draw from these spots to the corresponding spots on the vertical line at the side, and you will have the cutting planes

of the transoms represented on the body-plan; they will incline or cant downward from the centre-line towards the outer ends (*see the body-plan of the* 400 *ton ship, Plate* XXIII.) as much as the plane of the transoms in the sheer-plan cants upwards. Having got the plane of the transoms drawn on the body-plan, proceed and set off the fashion-timber. Take the distance from the centre-line of the floor-plane, along the fore cutting line, to where it is crossed by the lower transom; set this off from the centre-line of the body-plan upon its respective transom, and in the same manner set off the fashion-timber on the plane of the other transoms, and through these spots draw the fashion-timber in the body-plan. The inclined lines which represent the plane of the cant-transoms must be marked on the fashion-timber mould, and on the fashion-timber when it is worked, in order that it may be fitted to its proper place on the ends of the transoms.

The transoms should always be canted up in this manner, as it not only makes their bevellings less, but also, by throwing their ends up into a broader part of the vessel, it reduces their curvature, and makes it less difficult to prepare proper pieces of timber for the transoms. The bevellings of the transoms are commonly taken from the buttock-lines with a bevel, the stock of the bevel being laid in the direction of the plane of the transom, and the tongue brought in that of the buttock-line upon the thickness of the transom. The operation of laying down the cant-transoms, and taking the bevelling, is illustrated by *Fig*. 130, *Plate* VII., where the transoms are distinctly represented in the three different planes, and the fashion-timber drawn on the body-plan; the bevel is represented as lying at the first buttock-line on transom 2; the line *a a* comes to the vertical dotted line when the transoms are up. If we square up the point *d* to *c* in the sheer-plan, then the perpendicular height *g h* in the body-plan should be the same as the height of the point *c* in the sheer-plan, otherwise the work is not correct.

The Cant-Frames.

The cant-frames have no floors crossing the keel, as they are used before and abaft the square frames, as it would be difficult to find proper floor-timber with sufficient rising to make square frames for those parts of the vessel. The cant-frames not only supply the place of the square frames, but also serve to bind and strengthen the quarters and buttocks better than by separate timbers; for, owing to the inverted conical form of the bow and stern under the load-water line, it is evident that all the timbers required to fill up the bow and quarters above water cannot be brought down to the keel or dead-woods. At the same time, it is necessary that some of them be brought down to the dead-woods, and well fastened to the same. As one piece of timber cannot be obtained to reach from the gunwale to the keel at the bow or stern, more than at midships, you must build together a half-floor, and all the necessary futtocks, and construct a kind of half-frame to set up at this part of the ship. Also, as the vessel rounds-in very quickly near the bow and stern about the load-water line, if the plane of the sides of these timbers were at right angles to the keel, there would be much of the timbers dressed off in giving them the proper bevel on the outer and inner edges; this is therefore to be avoided as much as possible, by canting these timbers so as to have the planes of their sides nearly square to the ribbands. Accordingly they are called cant-timbers, and frames composed of these timbers are called cant-frames.

Vessels of about 200 tons should have two completely formed cant-frames abaft, and one forward, and large vessels may have three or four, according as they are sharp or full, and the convenience of getting proper crooks to make the after square frames as far aft as possible; to effect which, and where it is difficult to get proper naturally crooked floor-timbers, a good deal of fillings or choking pieces are employed to form the floor. These pieces, however, are too often very carelessly fitted, which makes a bad piece of work; at the same time, the building of floors cannot be altogether avoided, owing to the scarcity of the natural-grown crooks.

The cant-frames serve the same purpose that all the others do, viz. forming the vessel at their stations. There are two methods of laying them down on the plan: the first and most simple, although not exactly so correct, is by means of the water-lines—and the second, by the level ribband-lines. Their cutting lines, in the floor-plane, are the same for both methods, the difference being in the method of pricking them to the body-plan. To lay them down, draw the straight lines in the floor-plane to represent the planes of the cant-frames, gradually increasing the cant or inclination, as they are each farther from the foremost and aftermost square frames. The cant-frames may now be measured from the water-lines, in the same manner as the fashion-timber is measured from the level transoms, *i. e.* take the distance from the centre-line of the floor-plane along the plane of the cant-frame, to where it is intersected by the first water-line; set this distance from the centre-line of the body-plan on the respective water-line, and so on with the second and all the other water-lines, and you will have a spot on each water-line through which to draw the cant-frame; but a spot will also be required at the lower and upper height of main-breadth, and at the top-height, which is found thus:—Square up to the sheer-plan, perpendicular lines from where the cant-frame in the floor-plane cuts the main and top-breadth lines; take the main and top-height of breadth at these lines, set them up on the centre or side-lines of the body-plan, and square them across the frames parallel to the base-line. Proceed to the floor-plane, and take the main and top-breadth of the cant-frame, set them on their respective lines of height, which have now been drawn in the body-plan, and you will then have all the necessary spots or of-sets through which to draw the cant-timber in the body-plan.

On pricking the Cant-timber off from the Level Ribbands.—The level-ribbands mean the diagonal ribbands measured square or level off from the centre-line of the body-plan, in place of measuring down the diagonal. They terminate at the spot where the diagonal ribband touches the centre-line forward and aft in the floor-plane, as done on *Plate* XXII. Measure from the centre-line of the body-plan to where the first diagonal is cut by the foremost square frame, keeping the line between the two points of the compasses level, or parallel to the base-line; set this distance very exactly off from the centre-line of the floor-plane on the foremost frame. Return to the body-plan, and take the square or level distance from the centre-line to where the first diagonal is cut by the next frame; set this off from the centre-line of the floor-plane upon its respective frame, and in the same manner prick off all the frames, and the level ribbands may be run or drawn from end to end of the floor-plane; but it is only necessary to run them two or three frames abaft the foremost square frame, and before the aftermost square frame

in the after body. When you have drawn part of the first level ribband forward and aft, proceed and prick off the second diagonal, also the third and fourth, in the same manner. The cant-frame is then to be pricked off. Let the level-ribbands be marked L R (*Fig.* 131, *Plate* VII. *at the end of this volume*), M B the main-breadth line, and L H the lower harpin in the body and floor-plane. Suppose P to be the foremost square frame; let the line C T be a cant-frame, of which we wish the true mould in the body-plan. The first thing to be done is to draw perpendicular lines from where the cant-frame in the floor-plane is cut by the level ribbands, as the dotted lines *a e*, *b f*, *C′ g*; and also the lines *d h* and T *i*, from where the lower harpin and main-breadth lines cut the cant-timber. Then take the distance *e a* from the floor-plane, and set it from the centre-line of the body-plan to where it meets the first diagonal in the body-plan, as *e a*; next take the distance *b f* from the floor-plane, and set it also off from the centre-line to the second diagonal. In like manner, make *h d* in the body-plan equal to *h d* in the floor-plane; also make *i* T in the body-plan equal to *i* T in the floor-plane; from these points, *a b c* on the diagonals, and *d* T on the L H and M B line, square out lines parallel to the base-line. Return to the floor-plane, and measure from its centre-line along the cant-timber C T, to where it is cut by the first level ribband-line; that is, take the distance C *a* from the floor-plane, and set it from the centre-line of the body-plan along the line *e a*, and it will extend from *e* to *a′*, that is, the distance *a a′* in the body-plan will be the versed sine of the angle *a* C *e*, *a* C being radius. In like manner make the distance *f b′* in the body-plan equal to *c b* in the floor-plane; also *g c″* in the body equal to C *c′* in the floor-plane; *h d′* = C *d*, and *i* T′ = C T in the floor-plane; then draw through all the points *a′ b′ c″ d′* to T′ in the body-plan, and you will then have the moulding edge of the cant-timber or frame in the body-plan; also, if you draw the dotted curve through all the points *a b c′ d* to T, you will have the square view of the cant-timber, as it will appear in the ship when set up.

The correctness of the above method of pricking off the cant-frames from the level ribbands is rendered obvious thus:—Suppose the transverse sections of the ships between ⊕ and C′ are the same, and represented by frame ⊕ in the body-plan; then let it be required to find the mould of a timber or frame to cant in the direction C′ T′ (*see the floor-plane*, *Plate* VII. *Fig.* 131). This of course is done in the same manner as we did the other; but here it is more apparent that it matters nothing how much cant the frame may be placed with. The square view of this cant-timber, when placed in the ship, and the viewer looking from forward or aft, is the same as the midship-frame, for it must not extend beyond it, that is, the curve *q s* ⊕ *u* T; but the proper curve of the cant-timber, and to which the mould must be made, is the curve *q′ s′ u′* T′ in the body-plane, which is called the extended plane of the cant-frame. Now it will appear that the distance X T′ in the body-plan is = C′ T′ in the floor-plane; therefore when the plane T X in the body-plan is brought into the position T′ C′ in the floor-plane, the point T′ in the body-plan will coincide with T in the floor-plane; also the points *u′ s′ q′ z′* in the body-plan will coincide with the points *u s q z* in the floor-plane, as they are on the same level, or at the same height as the points T *u s q* in the body-plan.

Having explained to the reader the manner of laying down the cant-timbers, without perplexing him with useless demonstrations of the nature of these sections, we may observe, that all these crossings and layings down, by various lines and methods, serve as so many tests to try the correctness of the square frames, the ribband and water-lines. It need be thought no strange thing, if some of these require a trifling alteration before the cant-frames are got quite fair. We have merely laid down one cant-timber before the foremost square frame, which is sufficient; for, if the learner understands how to lay off one cant, he understands how to lay off any number, as they are all done in the same manner, the principle being the same. I consider the method of laying them off from the level-ribbands, a more correct and masterly job than that of laying them off from the water-lines.

It may be necessary to remind the reader, that the proper stepping of the cant-timber on the stem requires some little attention. He will be aware that the cant-timbers, as they are farther before the foremost square frame, must be drawn as much up on the line which represents the half-thickness of the stem in the body-plan, as the rising of the rabbet of the stem in the sheer-plan, at the proper station of the cant-timber, is above the upper edge of the keel. But to find the proper spot to draw the foot of the cant-timber to in the body-plan, you must first square up to the sheer-plan the exact spot where the cant-timber in the floor-plane cuts the line which represents the side of the stem; then take the height from the straight line of the keel up to the lower or outer edge of the rabbet of the stem, on the station of the cant-timber which has just been squared up, and set this height from the base-line of the body-plan up on a line which represents the angled half-thickness of the stem, according to the angle of the cant-frame; take the thickness of the bottom plank in the compasses, and from that point sweep a small circle inwards, and to the back of this circle the foot of the cant-timber must be drawn. The cant-timbers are drawn in the body-plan of the ship of 347 tons (*Plate* XXII.) which is given as a finished example. The square measurements of the cant-timbers are set off on the body-plan of the schooner (*Plate* XV.) foreward and abaft. I generally lay the cant-timbers off when laying down the plan in the moulding-loft. Sometimes the side view of the cant-timbers is represented in the sheer-plan, but it is of little consequence, farther than to give a better idea of the form of the bow and quarter of the vessel, as she will appear when the frames are set up. To find the proper spots in the sheer-plan through which to draw the cant-timbers, square up the spots where they cross the water-lines and the harpins in the floor-plane, and through these spots draw the cants in the sheer-plan (*See Plates* XXII. XXIII. XXIV.) where the cants are drawn in the sheer-plans. The fashion-timber may also be drawn in on the sheer-plan very exactly, by squaring up the exact spots where it cuts the water-lines and buttock-lines in the floor-plane, to their respective lines in the sheer-plan.

To draw in the Stepping or Bearding-line.—This is a curved line drawn on the sheer-plan at the stern-post and dead-woods, and is used for forming a kind of chack or rabbet on the dead-wood, on which to rest the heels of the cant-timbers. In principle, it is nothing other than a buttock-line cutting the vessel very near the middle. To draw

it on the sheer-plan, take the height of the foot of the different frames where they cut the line which represents the side of the stern-post on the body-plan, and set these up from the upper edge of the keel on their respective frames in the sheer-plan, and then through these spots draw the curve, and it will give the line required, as represented by the curved line at the heel of the keel and stern-post, extending from frame 22 to 28. (*See Plate* XXIV.)

To draw the Cutting-down Line.—This line is drawn at the determined deepness of the breech of the floor-timbers, *i. e.* their deepness at the keel, and is commonly run in the moulding-loft. It should be marked on the floor-mould of all the frames, that the workman may know exactly what timber will answer to make a floor for his mould, as he will know what height the breech of the floor must be above the keel, in order that the under side of the kelson may lie fair upon the floor-timbers. The cutting-down line on the sheer-plan is commonly drawn to represent the lower edge of the kelson.

To prick off the cutting-down line, we have only to take the deepness of the floors in the compasses, and place them square to the different frames, shifting them a little till the one point is in the frame and the other in the side-line of the stem or stern-posts on the body-plan; and then, marking the spot of the compass point on the side-line of the stem or stern-posts, take the height of that spot above the base-line, and set it up from the upper edge of the keel on its respective frame in the sheer-plan, and so on with all the other frames; through all these spots, draw the line in the sheer-plan.

Thus in the body-plan of the 500 ton ship, *Plate* XXIV., observe the small letters $a\,a'$, $b\,b'$, $c\,c'$, $d\,d'$, &c.; the dotted line joining the letters stands perpendicular to the frames at the points a, b, c, d, &c., and the distance $a\,a'$, $b\,b'$, $c\,c'$, &c. is equal to the deepness of the floor-timbers; the letters $a'\,b'\,c'\,d'$, &c. on the side-line of the stem, represent the height of the upper sides of the different floor-timbers; therefore, if we take these heights and set them on their respective frames in the sheer-plan, we shall have the points $a'\,b'\,c'\,d'\,e'\,f'$, &c. in the sheer-plan at the bow, and the dotted line drawn through these spots is the cutting-down line; also the small figures 28, 27, 26, 25, &c. in the dotted line in the after body, shew the same thing.

It must be observed, that the cutting-down line, taken in this manner, will only answer for a portion of the length of the middle of the vessel; for owing to the great rising of the floors near the ends of the ship, it is almost impossible to procure pieces of timber with sufficient crooks; therefore timber much straighter than the proper curve of the floor is used, and to make them answer, chocks are put upon the lower side of their breech, so as to raise them up; and as the floor-timber must, notwithstanding the chock, have a sufficient thickness of itself, this will raise the cutting-down line higher than if the floors were sufficiently crooked to answer the moulds, which also carries the dead-wood higher; therefore, to make the cutting-down line correspond with what it must be when we come to build the vessel, it requires to be drawn a little higher than what is marked by the measurements. The proper cutting-down line is marked on the sheer-plan (*Plate* XXIV.), and is considerably above the cutting-down, as measured from the body-plan.

To mould and bevel the Quarter-timber.—The operation of laying down and finding

the bevels of the quarter-timber, is rather more difficult than most of the other timbers. Owing to its particular shape, twist, and bevel, and also the situation in which it is placed in the vessel, to lay it down properly, to understand thoroughly the nature of its bevellings, &c. will require the particular attention of the learner; at the same time I trust I shall explain this operation in an easy manner, and which, if followed out, cannot fail to be sufficient to make him master of the whole affair.

The method proposed is as simple as can possibly be adopted, and near enough to the truth for any practical application whatever.

It is only for vessels of about 300, 400, or 500 tons and upwards, that we require to be so very particular with the moulding of these timbers. The eye of the workman, assisted only by the fore-and-aft mould, will direct him how to fashion and bevel the quarter-timbers of any smaller vessel. A good workman would perhaps have the timber dressed and hoisted up in its place, in the time required to lay it down in the moulding-loft, and make the mould for it. But when the ship is of considerable size, this much cannot be said. It is then the best way to proceed as correctly as possible with the moulding and bevelling of the quarter-timber; in this case, we shall find it the most expeditious in the end.

The quarter-timber (referring to the plan of the 500 ton ship, where we have laid down the quarter-timber, *Plate* XIV.) rests with its lower end on the wing-transom, where it is cut by the fashion-timber, and extends upwards to the top of the stern, raking aft, and inclining inwards with its top to the centre of the ship. Cant-transoms are drawn on this plan—(*see the Sheer-plan.*) The dotted line C D B is the after side of the quarter-timber at the outer corner, and may be taken as its moulding-edge in a fore-and-aft direction.

The first thing to be done is to draw the dotted line A B in the sheer-plan, parallel to the keel, the point B being exactly at the spot on the wing-transom where the after edge of the quarter-timber foot joins it. Next, from the point where the under side of the poop-rail cuts the after edge of the quarter timber, square down to the dotted line A B, the dotted line C 1; also, from where the under side of the poop-gunwale, under side of the main-rail, under side of the main-gunwale, the upper height of breadth line, &c. cuts the after side of the quarter-timber, that is, the line C D B, let fall the perpendicular lines 2, 3, 4, 5, 6, and 7. This much being done on the sheer-plan, transfer the quarter-timber line C D B to a more convenient part of the paper, and draw the dotted line A B (*Fig.* 4) to represent the line A B on the sheer-plan, to which the former must be drawn parallel. On A B (*Fig.* 4) erect the perpendicular 1, 2, 3, 4, &c. corresponding to those on the sheer-plan; make the distance 1 B (*Fig.* 4) equal to 1 B in the sheer-plan. If the sheet of paper is fixed on a drawing-board, and a T square used for drawing the lines perpendicular and parallel to each other, all these points may be squared down from the sheer-plan. As this is the most proper way of proceeding, I shall describe it accordingly. Having the vertical lines 1, 2, 3, &c. squared down to *Fig.* 4, measure the height of the intersection of the quarter-timber with them, above the line A B in the sheer-plan, and transfer these heights to the same lines in *Fig.* 4; then draw the line C *a b*, D *c*, *d e* B, for the moulding-edge of the quarter-

timber; draw with their proper sheer the lines C *u*, *a v*, *b w*, D *x*, *d y*, and *e z*, all of which are to represent heights, at which breadths of the vessel are to be taken, and are represented by the lines marked with the same names in *Fig.* 5. The line *d y* is parallel to A B; it is intended to form a horizontal section of the ship at that height. In order to render the figure as distinct as possible, draw in a part of the stern-post E (*Fig.* 4); draw the short line F B with the cant-up of the transoms, and it will represent the upper edge of the wing-transom; also draw the face of the fashion-timber marked G. The off-sets for these are got by squaring them down from the sheer and floor-plane to *Fig.* 4.

Proceed next to draw some of the lines in *Fig.* 5. Having drawn a straight line for the centre-line, square down to it a few of the after frames, as 20, 22, 24, 26, 27, 28, and 29; square also the point *e* (*Fig.* 4) down to the centre-line of *Fig.* 5, and it will be the termination of the main-breadth line, which is now to be transferred from the frames in the body-plan to their respective frames in *Fig.* 5.—(*Note.* By main-breadth line is meant the line which limits the extreme side of the vessel, exclusive of the thickness of the plank; this line is sometimes called the main half-breadth line, because only one half of the vessel is laid down in the floor-plane.)—After the main-breadth line is drawn in *Fig.* 5, take the height of the line *d y* (marked also thus, ×——×) above the wing-transom (*Fig.* 4), and set it above the wing-transom in the body-plan of the vessel, at which height square across the line ×——× (*see the Body-plan.**) Now the half-breadth of the ship at this line is the distance from its intersection with the frames to the centre-line of the body-plan; by transferring these distances to *Fig.* 5 on their respective frames, we shall have spots through which to draw the line marked ×——× in *Fig.* 5. In drawing this line, employ the same mould which drew the main-breadth line, and its termination is the point *d* (*Fig.* 5). Draw a straight line from *d* to the centre-line, also perpendicular to the centre-line; mark this line with ×——×, for it is only the representation of the same line in the body-plan. It so happens, that there is a place in the counter of all regular built square-sterned vessels, at which, if a line or straight-edged batten be applied across from the one quarter-timber to the other, it will touch all the timbers; or, in other words, the counter will be quite square across, and have no back round. This straight place is generally about half way up the counter, where the centre stern-timbers cut a line drawn across from the two quarter timbers; therefore the line marked ×——×, extending from *d* (*Fig.* 5) to the centre-line, is the termination of the counter when the vessel is cut by the horizontal plane represented by the line marked ×——× in *Fig.* 4 and in the body-plan. The advantage of this line may be conceived thus: If we find the bevel of the timber where this line cuts it, we can then apply the bevel-stock with certainty in bevelling it at all the other required places; but without a knowledge of this line, and its particular intersection with the quarter-timbers, and as there is not another square part which is straight across the stern, we could not bevel the quarter-timber with any degree of nicety.

* In lettering this plate, the cross marks on the line in the body-plan referred to have been overlooked. The reader is therefore requested to make two crosses on the line which extends from the centre-line of the body-plan (at the upper part of the circle of the rudder-case in the first counter), to the letters *t d* on the quarter-timber.

Having drawn that part of the line marked ×——×, in *Fig.* 5, which is perpendicular to the centre-line, next represent the breadth of the vessel's quarter at the height of the line marked D *x* (*Fig.* 4), which represents the main-gunwale; it is therefore marked *Main-gunwale* in *Fig.* 4, and M. G. for abridgement in the body-plan, where it terminates at the point D. Take the breadth from the centre-line, to where frames 22, 24, 26, &c. are cut by the line M. G. in the body-plan; transfer the same to their respective frames in *Fig.* 5, and through these spots draw the line M. G., ending at the point D. In like manner draw the other breadth-lines in *Fig.* 5, corresponding to the other lines of height represented on *Fig.* 4—of course the termination of these lines on *Fig.* 5 is got by squaring down from *Fig.* 4 the points C, *a*, and *b*. We may now lay off the wing-transom F B, and the part of the fashion-timber G. Next start at the point B, *Fig.* 5; draw the line B *e d c* D *b a* C, which will be the moulding-edge of the quarter-timber, when squared down to the horizontal plane of the paper, the edge of which plane may be the line A B, *Fig.* 4.

The moulding-edge of the quarter-timber being now represented on *Fig.* 5, proceed to draw it on the body-plan, on which the dotted line A B represents the line A B in *Fig.* 4. Take the height 1 C in this figure, set it perpendicularly up from the line A B in the body-plan, and so on with all the other heights, as 2 *a*, 3 *b*, &c. At all these heights, above the line A B, square lines across to the centre-line of the body-plan—(these lines we have left out, as they would tend to confuse the figure too much.) Proceed to the corresponding lines C 1, *a* 2, &c. *Fig.* 5; take the distance of the points C *a b d*, &c. from the centre-line, and mark them on the corresponding cross lines in the body-plan; and through these points draw the line C *a b* D *e* B, and you will then have the moulding-edge of the quarter-timber represented in the body, or plan of projection.

The next object is, to lay down the thwartship-mould of the quarter-timber. (The fore-and-aft or face-mould may be made to the line C D B (*Fig.* 4), which, although not exactly true, is sufficiently near, if we allow a little more length to make up for the difference between the length of a straight and vertical line, extending from the line A B in the body to the top of the quarter-timber, and the line C D B, which is inclined thereto, and is therefore longer.) And we are in some measure prepared for the same.

It will appear evident to the reader, that other methods might be employed to form the fore-and-aft mould, so as to note the tumble-home of the quarter-timber on it, and consequently there would be no occasion to employ a thwartship-mould; but the method proposed is simple, and more easily applied in practice than any other which I have seen used, and is preferable to that which requires brackets. A face and edge mould is always used in the ingenious art for hand-railing in stairs.

We have now to lay off the moulding-edge of the quarter-timber as extended on a horizontal plane, which is represented by the line C′ *a*′ *b*′, D *d*′ *c e*′ B (*Fig.* 7, *Plate* XXIV.) *i. e.* is the horizontal view of the quarter-timber. Supposing it to be cut and hinged at the point D (*Fig.* 4), and then straightened out and laid on the plane A B with its after edge upwards, in which case the line C C B (*Fig.* 4) is supposed to come straight. First take the distance C *a* (*Fig.* 4); set it off from the point 1 (*Fig.* 7) to-

wards the right. Return again to *Fig*. 4; take the distance from *a* to *b*; set this from 2 towards the right (*Fig*. 7),—we shall then have point 3. Return again to *Fig*. 4; take the distance from *b* to D; set this from point 3 (*Fig*. 7) towards the right,—we shall then have the point 4; and in the same manner proceed to transfer all the other points from *Fig*. 4 to the centre-line of *Fig*. 7. Square lines across at these points; then take the breadth of the stern at all the lines marked 1, 2, 3, 4, &c. in *Fig*. 5, and set them from the centre-line of *Fig*. 7, on the cross lines of the same numbers, as 1, 2, 3, &c.; you will then have the points C′ *a′ b′* D *c′ d e* B (*Fig*. 7), through which to draw the moulding-edge of the quarter-timber. To this line a mould may now be made; it must of course be cut and hinged at the point D, so that it may fold against the counter and stern end of the quarter-timber, as represented in *Fig*. 6, K *h* P being the edge of the mould when folded up against the after side of the timber.

In order that this thwartship-mould may answer for both sides of the ship, the joint at the hinge must be perfectly square across from the centre-line (*see Fig*. 7), where we have marked the hinges and the joint. Observe that the mould should be kept very broad at this place, and the centre-pin of the hinge lying perfectly square across the ship, otherwise the mould will go in or out at the top when folded up from the straight, and give a false cant or tumble-home. The hinge should be made so that the mould will fold either backwards or forwards; and the propriety of this method of hinging the mould will be evident to the reader without any farther explanation. This much, then, for the construction of the face and edge mould, or, as they may be called, the side and thwartship moulds.

We shall next consider how the bevellings of the side of the timber and the back-round of the stern are to be laid off.

Suppose we set 12 inches forward from the line C D B (*Fig*. 4), and square off that line as *p q*; strike in the line *q r s* to represent the fore edge of the quarter-timber; square down to *Fig*. 5 the intersections of this line with the different lines of height, to their respective breadth-lines; then draw from point to point, thus marked on the breadth-lines in *Fig*. 5, the dotted line *q r s*,—we shall then have the fore edge of the quarter-timber represented on *Fig*. 5; and as this line cuts the breath-lines further forward in the vessel (which breadth-lines are not parallel to the centre-line, but get under as they go forward towards the middle of the ship's length), the difference between the half-breadth of the vessel at the after edge of the quarter-timber, and the half-breadth taken at its fore edge at any particular line of height, is how much within or without a square the timber must be hewed at that spot; and the dimension or degree of bevel must be taken in this case in the same direction that the line of height cuts the quarter-timber in *Fig*. 4; but as this will not be square across the timber, it will be necessary to lay down both sides of it in the body-plan, *i. e.* its fore edge, which of course, from being farther forward, will extend without the after edge. When the fore edge is thus laid down, it will be easy to shew how the square bevel at any spot may be found and applied.

In laying down the fore edge of the quarter-timber in the body-plan, proceed in this manner—(*See Fig*. 5, *Plate* XXIV.)—Take the breadths from the centre-line, to where

the dotted line *q r s* cuts all the breadth-lines; transfer these to intersect (when measured square across from the centre-line) their corresponding lines in the body-plan; and through these spots draw the line marked *q r s* (*see the Body-plan*), which will represent the fore edge of the timber. The distance between *q r s* and the line C D B is how much the bevel of the quarter-timber is, without a square, applied off its after side, which is supposed to be square across the ship; but this bevel is taking the quarter-timber to be moulded 12 inches on the square, from the wing-transom to the top, which is never the case in practice, the timber being tapered, as represented in *Fig.* 6; therefore it will not be so much without a square at the top, as represented by the line *q r s*. In the body-plan, however, this will appear, with its corrections, when we have shewn the method of marking the bevels on the bevelling-board.

To mark the square Bevellings of the Timber on the Board.—Let the bevel board be 12 inches in breadth, and any convenient length; make its edges quite straight and parallel, (see *Fig.* 8, where *a b c d* represents the bevel board.) Now suppose we wish to take the square bevel of the timber at the point *d* (*Fig.* 4), that is, a bevel in the direction of *d t*,—First make a square line across the bevel-board, as *e f*; then proceed to the body-plan, and on the line C D B find the spot *d* (corresponding to *d*, *Fig.* 4); draw the short line *d t*; square off the timber at *d*; then take the distance *d t* from the body-plan, and set it on one edge of the bevel board above the square line *e f*, that is, the point *t*; draw the line *e t*, and it will be the bevel of the timber as required. Now, if we bring the blade of the bevel to coincide with the line *e t*, while the stock is lying against the edge *a c* of the bevel board, we shall then have the bevel to apply to the timber: it makes no difference what breadth it may be at *d t* (*Fig.* 4.) The bevels may be found for any other part of the quarter-timber in the very same manner—but observe, when applying them to the timber, that the stock of the bevel is placed exactly out of winding with a batten nailed across the after side of the timber at the spot *d* (*Fig.* 4); for the principle of the method now described rests on the assurance that the stock of the bevel lies square across the centre-line of the vessel; and as the quarter-timber is square in this direction at *d* (as before observed), in bevelling the side of the timber you must always keep the stock of the bevel lying in the same position.

Thus much then for the bevel of the side of the timber. I shall, in the next and last place, lay off the back-round. From what has now been said on the principle of taking square bevellings, the reader will easily perceive the application of the same principle in bevelling the timber, so as to answer the intended back-round of the stern.

The first thing to be done is to draw the round of the stern; this is generally about 3-8ths of an inch for every foot of the breadth of the stern. With a sheer-mould of this curve, draw the lines C′ *c*′, *a a*′, *b b*′, &c. on *Fig.* 5; next draw the dotted line *m n*, to represent the inner side of the quarter-timber, supposing it 12 inches thick; then by taking the small distances between the square dotted lines and the back-round lines at all the intersections of the line *m n* with them, as the small distance *m o*, and setting this square off from the after edge of the quarter-timber in *Fig.* 4, we may then draw the dotted line *m n* in the same figure—the distance between which and the line C D B, will be how much back-round there is on 12 inches, and this of course may be marked on the

bevel-board, and reduced so as to apply; square off the side of the timber, in the same manner as before shewn for the bevellings the other way.

Having now gone over most of the intricate parts of the draft, proceed to finish the sheer-plan, by first placing the masts, bowsprit, &c. and completing the head and galleries, as shewn by *Plates* XXII. XXIII. and XXIV.

I commonly mark the station of the masts, and draw in their centre-lines, as soon as the sheer-plan is sketched in; but it will be sufficient if we leave this until we are ready to finish the plan, and draw in the deck-beams, &c.

If the vessel is intended for a ship or bark, divide her length on the load-water line into eight equal parts, and set the main-mast 1-14th of the length abaft the middle division—the fore-mast 1-8th of the length abaft the outside of the rabbet of the stem—the mizen-mast 3-8ths of the distance between the centre of the main-mast and the outside of the rabbet of the stern-post set forward from the same. The rakes abaft should be—

The fore-mast,	$\frac{1}{4}$ inch for every foot of its length.		
The main-mast,	$\frac{1}{2}$ inch	do.	do.
The mize-nmast,	$\frac{3}{4}$ inch	do.	do.

If the vessel is intended for a brig, place the centre of the main-mast 1-8th of the length of the load-water line abaft the centre of the same, and the fore-mast 1-6th abaft the rabbet of the stem. The rakes are the same as a ship's fore and main-mast.

If the vessel is intended for a schooner, place the centre of the main-mast 1-8th of the length aft the centre, and the fore-mast 2-9ths of the length of the load-water line abaft the rabbet of the stem. The rakes should be—

The fore-mast,	$\frac{3}{8}$ inch for every foot of its length.		
The main-mast,	$\frac{3}{4}$ inch	do.	do.

If the vessel is intended for a smack, place the mast 1-7th of the length of the load-water line before the centre, or, more correctly, place the centre of the mast in the middle, between the proportions of 1-3d and 3-8ths of the length of the load-water line abaft the rabbet of the stem, and give it a rake aft of one-half inch to the foot of length.

Note.—The above stations of the masts are to be marked on the load-water line, and the rakes taken from the same. For other particulars relating to the place and dimensions of the masts, see the subsequent treatise on the principles of masting.

On the Head and Cut-water.

The head projects outwards before the front of the stem, to which it is fixed by the cut-water. This appendage to the ship is designed for ornament—at the same time it is rendered useful when the vessel exceeds 150 or 200 tons.

There are three kinds of heads,—1*st*, The Figure-head is one on which is placed the figure of a man, woman, or the like, &c.; 2*d*, The Billet-head or Scroll-head is one finished with two scrolls or volutes—(*see the Schooner, Plate* XVI.); and 3*d*, the Fiddle-head, which is finished with only one scroll or volute, having the spirals turning inwards to the vessel—(*see the Brig of* 220 *tons, Plate* XIX.) The first of these methods of ornamenting the front of the vessel seems to be most in vogue at present; almost all

vessels of considerable size are finished with figure-heads. The billet-head is in general more admired than the fiddle-head. A neatly-set and duly-proportioned head gives a degree of symmetry and elegance to the general appearance of the ship, but has a reverse effect if it is not duly proportioned to the size of the vessel, or placed with the proper sheer.

From the great diversity of taste, it would be impossible to execute this and various other ornamental parts of the ship, so as to coincide with the ideas of beauty in every person, or even with those of the same person at different times. Yet there are certain appearances which strike the fancy of a great number of beholders, and in these appearances the diversity, arrangement, and proportion of the various parts, are harmoniously combined.

Custom has its effect in forming the taste. We certainly think a new fashion ridiculous, because it differs from what we have been accustomed to. Different places hold different fashions. What might be thought beautiful in one place, may be considered the reverse in another,—what we might think a neat and duly proportioned head and cut-water, may be considered preposterous by our neighbours and contemporaries.

In those sea-ports where large vessels are commonly built, and which are higher in proportion to their length than small vessels, the form of the cut-water is straight, and the head appears deep and short, and not to have the due projection. Again, in those places where small vessels are built, they give the head a good projection, and make the cut-water hollow, which gives it a light and airy appearance. This is found to answer better than if they were made in the same proportions as the large vessels; for if the head is deep, and the cut-water straight, so much of it is brought into the water, that the whole is sometimes carried away by the sea striking against the side of the head and cut-water.

On the Proportions of the Head and Cut-water of Vessels from 100 *to about* 250 *or* 300 *tons.*

The projection of the head, measured along the sheer of the vessel, from the fore part of the main-stem to the back or shoulders of the figure, may be 1-13th part of the ship's length for tonnage, and the deepness of the cut-water proportioned thus: —Take 1-16th of the ship's length on the load-water line (this is generally the same as the length for tonnage) in the compasses, and on the front of the main-stem, where it is cut by the under side of the bowsprit, as a centre, describe a semicircle downwards; draw a straight line from the centre to the circle, forming an angle of about 30 degrees with the perpendicular let fall from the front of the stem; and where this radius touches the circular arc, is the spot through which the hollow part or under side of the cut-water is to pass. Commence at the fore end of the keel, and draw the front of the cut-water upwards, gradually rounding it out, making it flatten towards the light water-mark, after which it must begin to curve inwards, until it cut the point in the circumference of the circle; it then begins to flatten, and approaches gradually to a straight, again begins to turn or round upwards, and at last ends at the lower part of the figure.

For the Size of the Figure.—Small vessels have commonly busts or half-figures, as these have a better effect than full figures on small vessels. The extreme length of the bust, including the scroll at the body of the bust, may be 3-8ths or 1-3d of the projection of the head, measured as above directed; and the extreme length of the half-figure may be one half of the projection, measured as above.

For the Height of the Lower Cheek-knee on the Stem.—The station of the lower knee on the stem will be regulated by the bow-port; this being first placed in the best position for taking in and out the cargo, the knees of the head must be shifted clear of it; but, in general, if you sweep the circle formerly used for determining the deepness of the cut-water round till it cut the inside of the rabbet of the stem, it will be the under side of the lower cheek-knee.

The rails are intended to steady and support the head and cut-water, and the straighter they are, the better they will effect this purpose; but as regular curves are more congenial to the form of the ship, which is composed chiefly of curved lines, and as these produce a better effect than straight lines, the rails of the head are made curving, being parts of cycloids and ellipses. The rails must run well with the sheer of the vessel, and not appear to droop down at their fore end; they should also have a regular taper from the bow to the figure. Their dimensions opposite the stem are—first, The depth or moulding dimension is 5-8ths of an inch for every foot of the whole length, and this is regularly diminished to 2-3ds or 3-5ths of that depth at the outer end. Their thwartship or siding dimension is 3-4ths of their depth or moulding dimension. The depth of the lower rail is about 4-5ths of the upper one, and tapered off towards the fore end in the same manner The cheek-knees should shew the same depth as the upper rail, and be regularly tapered towards the figure. The timbers of the head should be sided the same as the upper rail is moulded.

Having given the general dimensions of the principal parts of the head, proceed to draw it on the plan in the following manner:—Draw a line from the front of the main-stem at the under side of the bowsprit, with the same sheer as the vessel; on this line mark the projection of the head; then sketch in the figure; draw in the cut-water; draw a line from the shoulders of the figure to the spot on the bow of the vessel where you mean to run the upper rail, observing that this line has the exact sheer of the vessel. Divide the distance from the lower side of the lower knee at the stem up to this line into four equal parts, the lower of which will be the distance between the lower edge of the under or lower knee and the upper edge of the upper knee; make the second division the upper edge of the lower rail,—the third division the upper edge of the upper curved rail,—and the fourth division will be the upper or the straight rail. Having marked all these spots on the stem, through which the rails are to be drawn, take an elliptical mould, and draw in the rails, tapering them gradually as they near the figure. After this is done, draw the timbers of the head; these cross the rails in the inside, and stand vertical, as may be seen on the plans. (*Vide the book of Plates.*) The space between the cheek-knees is filled in with carved work, called the trail-boards. But it must be observed that the curve and length of the rails, as seen in the sheer-plan, are not their true curve and length. If moulds were made to these, they would

be found too short when tried on the ship; therefore it is necessary to lay down a line in the floor-plane to the proper length and curve of the rails. To do which, first square down the spot where the rail terminates on the bow in the sheer-plan to the top-breadth line in the floor-plane; also square down the point at the back of the figure, where the rails meet, to the centre-line of the floor-plane—(*see the plan of the* 300 *ton ship, Plate* XX.) Draw a straight line from this spot to the other vertical line at the top-breadth, and this line will represent the upper straight rail, or the fore-and-aft vertical plane of the upper curved rail. Divide the straight rail in the sheer-plan into any convenient number of equal parts; also divide the same line in the floor-plane into the same number of equal parts; at each of these divisions, draw the dotted lines at right angles to the lines which have now been divided; take the compasses and measure the curve of the rail from the straight line as a cord; set these measurements on their respective divisions from the straight line in the floor-plane; then through all these spots, draw the curve, and it will be the true mould of the rail, as required. The true mould of the lower rail, that is, the rail next above the upper cheek-knee, is obtained in the same manner.

To draw the Scroll, or Double Volute, for the Fiddle-head—(*see Plate* XIX. *Fig*. 1.—In finishing the head on the plan, the scale is so small, that it is necessary to draw the scroll or volute by itself on any unoccupied part of the paper, which may be done according to Mr. P. Nicholson's method, thus:—Make A B equal to the length; divide that distance into 23 equal parts; from the 13th division from B, or 10th from A, draw the line J K perpendicular to A B, intersecting in the point C; from the 14th division, draw the line L I parallel to J K; draw the straight line C E F D, dividing the angle A C J into two equal parts; on centre C, and radius C I, describe a circle for the eye of the volute or scroll; divide the distance C I and C H into three equal parts, as 1, 2, 3, 4; on H as a centre, and radius H B, describe the semicircle B J C; on I as a centre, and radius I C, describe the semicircle C A K D; on the point 1 as a centre, and radius 1 D, describe the semicircle D E; on 2 as a centre, and radius 2 E, describe the semicircle E F; on 3 as a centre, and radius 3 F, describe the semicircle F G; on 4 as a centre, and radius 4 G, describe the semicircle G H, and the outer edge of the fillet M will be completed. In the same manner, proceed to draw its inner edge; also the outer and inner edges of the fillet N may be drawn from nearly the same centres.

On the Proportions and Method of Drawing the Heads of Ships from 300 *to* 500 *or* 600 *Tons.*

I propose here to give the head rather a little more projection than is commonly given to the heads of large vessels, as they must have projection to look well. A raking head and cut-water will always look well; while its opposite (a short, upright, and deep head) looks stiff and disagreeable, however well the finish and workmanship may be executed. I have often found that the head appears to have more projection on the paper than when executed on the vessel, which may be owing to the spreading out of the rails at the bow.

The projection of the head from the rabbet of the main-stem (when the vessel has an upright bow) to the shoulders of the figure, should never be less than 1-11th of the ship's length on the load-water line; but if she has a fair rake of the stem aloft, 1-12th of the load-water line will be sufficient projection. In general, therefore, the projection may be a mean between these two proportions.

The proportioning of the projection of the head may also be found by the following method, which I think is preferable to the above:—Continue the load-water line before the stem; then take 2-15ths of the length of the load-water line from the rabbet of the stem to the rabbet of the stern-post, and set this distance forward from the outside of the rabbet of the stem, on the line of the load-water line; and at that spot square up a perpendicular line, and it will limit the extreme projection of the head, including the figure. Some vessels may have a projection of the head, measured in this manner, of 1-7th of the length of the load-water line.

The deepness of the cut-water in the throat will be regulated a little according to whether the figure is to be a full, a half-length figure, or a bust. If for a full-length figure, make the depth 1-13th of the length of the load-water line, and if a half-length figure, make the depth a mean between 1-13th and 1-14th, and for a bust-head 1-14th or 1-15th of the length of the load-water-line. The rails for these heads are proportioned as before. The full figure for any vessel above 400 tons should be as large as life, to have a fine appearance on the vessel. In general, the length of the figure is nearly 1-3d of the entire projection of the head beyond the rabbet of the stem at the load-water line.

Having given the best proportions for the head, we may proceed to lay down the head and cut-water of the 400 ton ship, *Plate* XXIII. Supposing the head and cut-water to be drawn on the sheer-plan, nearly agreeing with the above proportions, the object is to lay off the proper curve of the rails, as on the floor of the moulding-loft. First, let A be a point at the fore part of the main-stem under the bowsprit; B is the back of the figure; A O the radius line, forming an angle of 30 degrees with the perpendicular line A *b*; D B the straight rail, the lower edge of which is divided into six equal parts; B C a dotted line drawn from the shoulders of the figure to the spot where the lower rail joins the bow; it is divided into six equal parts, but any number of parts, as 8 or 10, will answer equally well. C E is another cord, divided into three equal parts. The same figures and letters are used for the corresponding parts in the sheer-plan and floor-plane.

Let fall a perpendicular from the point B in the sheer-plan, and it will cut the centre-line of the floor-plane in B; also let fall the point D in the sheer-plane, to intersect the top-harpin in the floor-plane at D′; then join D′ B′, and it will give the extended length of the top rail. Divide D B into six equal parts, as 1′, 2′, 3′, 4′, &c. the same as in the elevation, at each of these divisions; draw short lines perpendicular to D B in the sheer-plan, and D B in the floor-plane; measure the deflection of the rail in the sheer-plan at each of the short lines, as at N 1′; set this from the straight line D′ B′ in the floor-plane, also on the short line N 1 ; and in like manner measure the deflection of the rail at all the other divisions, and set them on their corresponding divisions in

the floor-plane; then through these spots draw the curves, and it will be the mould of the upper curved rail.

The plane of the lower rail is the line H C in the floor-plane; its curve is also pricked off in the same manner—only observe, that from the inclined position of the line C B in the elevation, it extends from B to H when laid horizontal; therefore C B in the sheer-plan is equal to C H in the floor-plane, at the same time C H is as much longer, according to the angle which it forms from the centre-line of the floor-plane. Divide C H into the same number of equal parts as C B, and having marked their numbers to correspond, as 10′, 11′, 12′, &c. draw the short lines perpendicular to C B and C H, and transfer the deflection of the rail from the chord C B in the sheer-plan to C H in the floor-plane; then through all these points draw the curve H I C′. Proceed in exactly the same manner for the curve of the piece C E of the rail which joins the bow of the vessel, which comes up and forms the knee of the cat-head. The vertical plane of the lower rail is the line H C′ E′ very nearly, with a small allowance on the portion C′ E′ for the round of the bow.

As it may be a little difficult to conceive how the curve H C′ I′ E in the floor-plane will become fair and unbroken in the sheer-plan, it may be laid off in this manner: —Draw the line B Q (*see the Floor-plane*) at right angles to B C; make B B′ equal to the rise or inclination of the line C B in the sheer-plan; then draw the line C B′, which will be equal to C H, on the sheer-plan of the head; take the perpendicular distance from the point C to the straight line marked E B; then, with this distance in the compasses, and centre C in the floor-plane, describe the arc X Y; then draw the dotted line B′ P, so as to touch the circle at the point P. Produce the line B′ P beyond F; with about 1-10th more in the compasses than the distance C E, and with point C as a centre, describe an arc cutting the line B′ P in F; then the line B′ P F in the floor-plane will be equal to E B in the sheer-plan, adding the length which it gains by the flanging out of the bow of the ship. Draw the line F C; divide it and C B′ into the corresponding number of equal parts, as the lines E C and C H; at each division draw the short perpendiculars to these lines F C and C B′; and on each set the corresponding deflection of the curve H I C S E. If through these spots a curve be drawn, it will be the proper mould of the rail, running fair and unbroken from the back of the figure to the cat-head.

On the Stern and Quarter Galleries.

As the sterns of almost all vessels are more or less ornamented and finished after some fashion or other, with either mouldings or carved work, or painted in imitation of the one or the other, and extended according to the taste of the builder and size of the ship, I shall offer an example of drawing the stern of a ship of 400 tons.

The sterns of sloops, smacks, schooners, and small brigs, are, according to the present proportions for building the sterns, found to be too shallow to allow stern-windows of a proper size to give light into the cabin. They are therefore finished in a plain manner, having often no ornament except the mouldings on the arch-board, and a small moulding nailed on the stern, forming an arch or semi-ellipsis.

Brigs, and all vessels above 200 tons measurement, may and should have stern-windows, which are of great advantage in ventilating and given light to the cabin. Vessels that are closely built up abaft, and having no stern-windows, very soon take the dry rot in the stern-timbers and quarters. I have often seen vessels much affected with dry rot about the stern and quarter in the course of three or four years. That this rapid decay is fostered by the closeness of the stern abaft the cabin, and from not having a proper ventilation of fresh air, cannot be doubted.

It is impossible to say what is the best form for the stern and galleries, it being a mere matter of fancy. Not only does every nation decorate and form the stern according to its own ideas, but every port has its own peculiar taste; and good judges will be able to know the place where a vessel has been built by the particular finish or form of the bow or stern.

Example to draw and finish the Stern and Galleries of the Ship of 400 *Tons*, (Plate XXIII.)

Before proceeding to draw the stern of the vessel, it must be considered whether she is to have a break or poop, or a flush-deck. If the vessel to which we have referred is built with a flush-deck, the knuckle of the quarter-timber, the whole counter, and perhaps the wing-transom, would answer better to be placed a little lower, particularly the knuckle of the quarter-timber and stern would require to be lower, otherwise there would not be sufficient room between the upper edge of the arch-board and the under side of the deck-transom to admit of proper stern-windows. The whole stern would be too shallow in proportion to its breadth.

Again, if the stern is drawn sufficiently low, so as to admit stern-windows without a break or poop, and a poop were to be added to the vessel, the stern would become too deep for its breadth and the size of the ship, and consequently have a bad appearance. Therefore, it is necessary to determine whether the vessel is to have a poop or flush-deck before beginning with the plan.

The height of the poop on the vessel (*Plate* XXIII.) is 4 feet 6 inches from the main-deck to the top of the poop-deck; there is a break downwards in the main-deck of 2 feet, which gives 6 feet between deck and beam for the height of the cabin.

Commencing first to draw the side view of the stern and galleries, and second, with the after view of the stern, draw the counter and quarter-timber agreeable to the direction before given (p. 179), making the stern, above the second counter, rake aft about 5 inches to the foot of perpendicular height, which is about 57 degrees of an angle with the level of the keel.

On a line drawn from the knuckle of the quarter-timber, set forward the thickness of the quarter-piece, and about 2-23ds of the ship's length, for the length of the galleries. Make the depth of the gallery not more than its length; for long low vessels, it is better to be in depth less than its length, as the depth 2-3ds of the length. Having thus set off the size of the gallery, the rail and windows are sketched in with the pencil, after the manner shewn on the plate, or any other. On any convenient part of the paper, so that the stern will not encroach on the lines of the floor-plane, draw the vertical dotted line H I for the centre-line of the stern, at right angles to which, draw the line

J K; on this set the breadth of the stern at the height of the poop-gunwale; (this breadth is obtained by squaring down to the floor-plane the spot of the poop-gunwale at the quarter-timber on the sheer-plan, and then measuring from the centre-line to the top-breadth line). From the points J and K, lines J L and K M are drawn, with the same tumble-home or inclination as the top-timbers of the poop. Measure down the quarter-timber in the elevation from the gunwale of the poop to the knuckle of the quarter-timbers or lower edge of the arch-board; mark this downwards from the points J and K, then draw the dotted line L M; find the breadth of the stern at that line (this is got by squaring a line down from the knuckle of the quarter-timber to the floor-plane, and then taking the distance from the centre-line of the floor-plane to the main-breadth line), and set it from each side of the centre-line of the stern on the line L M; and if it agrees with the breadth at the quarter-timber, as before drawn, take the distance of the wing-transom from the knuckle of the quarter-timber in the sheer-plan, measured down the counter, and set it down the centre-line of the stern-plan, from the cross line L M; and at that spot draw another square line parallel to L M; mark on the square breadth of the wing-transom at this place. Having found all these breadths, draw the quarter-timbers marked N N and N′ N′; also mark the point where these lines would meet, if continued above the stern (as the point X, near the under side of the main-chains in the sheer-plan); stick a small needle or pin in this spot, against which to rest the edge of the ruler or straight-edged batten, in drawing all the stern-timbers, &c. as these must all converge to this point. On the centre of the line L M, as a chord to the lower side of the arch-board, set up the curve of the arch-board, which should have a rise in the middle of one and a half inches for every three feet of the breadth of the stern at that place; then, with a sheer-mould or sweep that will cut the ends of the line L M, and pass through the point which has been set up in the middle, draw the round of the arch-board, and the mouldings on its upper and lower edges, extending the same without the quarter-timber as far as will be required for the breadth of the gallery. On the outer edges of the quarter-timber, draw the thickness of the plank and bends. On the extended part of the upper moulding of the arch-board, mark outwards from the outside plank 1-6th or 3-17ths of the breadth of the stem, measured from the outside plank at the upper edge of the arch-board, for the breadth or projection of the galleries on the stern, which should never extend beyond the extreme breadth of the ship. Then lay the straight edge or ruler against the pin at the point X; draw the outer edge of the galleries on the stern-plan; also divide the stern-windows on the upper edge of the arch-board; draw them up to the same point X; mark the height of the gallery-windows, measured on the slant, on the outer edge of the outer stern-window. With a mould or sweep that will give a rise of about two inches for every three feet of the breadth of the stern at the height of the top of the stern-windows, draw a line right across the stern, to mark the top of the windows, making the centre or middle window the highest, which should always be the case, as it is the broadest.

The architraves, and other ornamental parts of the stern and galleries, are now completed. There is generally a figure carved on each of the quarter-pieces, which is seen both on the stern and side view of the galleries. (*Vide Sheer-plan, Plate* XXIV.)

Having so far completed the stern-plan, the galleries are drawn in with ink on the sheer-plan, observing first to make what alterations on the height of the rails or mouldings may be necessary to make them correspond with the plan of the stern, by inspecting which it will be observed that the upper and lower mouldings of the arch-board round down a certain distance in coming from the side of the quarter-timber to the outer edge of the galleries at the points F and G.

The dotted curves in the floor-plane at the stern, marked 2 and 3, are the mould of the fore-and-afters at their corresponding rails in the sheer-plan. The timbers of the galleries are placed up and down between the windows.

In the plan of the 500 ton ship, *Plate* XXIV. the mouldings of the stern-windows, and the windows in the gallery, do not come down to the moulding of the upper edge of the arch-board, as there is a strake of 10 or 12 inches in breadth run round above the upper edge of the arch-board or second counter. On the upper edge of the strake, is wrought a moulding of 3 inches, and on it the architraves of the windows are butted.

Plan of the Inboard-work and Deck-lines.

The plan of the inboard-works exhibits a section of the vessel when cut lengthways. In this section are shewn the scarphs of the keel, kelson, &c., and the position of all the beams, breast-hooks, &c.; also the line of the different decks. Sometimes the inboard-work of the vessel is drawn by itself on a separate sheet of paper, but in general may be sufficiently represented by a plan of the decks, and drawing of the deck-lines, with a section* of the beams, kelson, &c. on the sheer-plan, as represented on the sheer-plan of the ships of 400 and 500 tons, *Plates* XXIII. and XXIV. *Plate* X. *Figs*. 1 and 1′, shews the inboard-works of the bow and stern-ends of a ship of about 350 tons; *Plate* XXIX. *Fig*. 4, shews the complete inboard-works of a steam-boat of 80-horse power.

In drawing the side-line of the beams on the sheer-plan, in order to construct the inboard-works, first run a line along for the centre-line of the deck, *i. e.* its height in the middle of the ship's breadth from stem to stern; then determine on the round of the beams, according to the rules laid down at p. 158, with a sheer-mould which will draw the proper round of the beams; draw a line for the upper edge of the midship-beam, and set off the inside breadth of the vessel at midships; also set off the inside top-breadth at all the stations of the beams, and measure the curve of each down from a tangent-line; then set this distance down from the deck-line in the sheer-plan at each beam, and draw a line round the sheer-plan, touching all these spots, and it will give the upper side of the ends of the beams; make a section of the ends of the beams from stem to stern. It will also be necessary to construct the deck-plan, that the position and dimensions of the hatches may be duly considered. From this plan, the length of all the beams may be taken sufficiently near to prepare and dress them to the proper round before they are put into the vessel; all which operations will be pointed out in the practical part of this work.

On the Planking.

The planking is that part of the structure by which the ribs or framing timbers are covered. The planks are made from timber cut into thin pieces, of from $1\frac{1}{2}$ to 6 inches in thickness—below that size they are generally called boards; they are plied completely round the vessel in a longitudinal direction, and laid close to all the timbers; their edges and ends are also trimmed in such a manner that they shall join so close to each other, that with the addition of a little oakum or other soft material drove into the seams, the water shall be entirely precluded from entering into the vessel.

The thickness of the planking should always be in due proportion to the magnitude of the vessel, particularly that of the length, it being found by experience that all ships of a long construction are more liable to strain, when lying on the ground with a heavy cargo on board, or going over a high wave, than other vessels with the same weight on board, but built on a shorter construction. It is also necessary that the planking of any ship should be of different thickness, and thickest on the parts of the vessel which are most exposed to strain, or where any particular binding is required.

The plank next the keel, commonly called the garboard-strake, requires to be a little thicker than on the flat of the bottom, and should be perfectly sound and free from shakes, as the backing at that part is seldom so complete as the other parts of the bottom. The butts in this strake, and the one next above it, should always be placed quite clear of the pump-well, the scarphs of the keel, and steps of the masts. Those on the floor-heads and heels of the second futtocks, commonly called the bilge-planks, are in number from two to six, according to the size of the vessel; they require to be of a good quality of timber, and as long as can be conveniently worked; they should be 1-3d or 1-4th thicker than on the flat of the bottom, this being the part where the bottom and sides are first joined, and where a great portion of the weight of the ship and cargo chiefly devolves, either when lying on the ground or afloat. These planks should be close fitted to the timber, the butts well shifted, and carefully fastened. From the upper edge of the bilge-planks to the thick-stuff under the wales, all the planking on the side betwixt the foremost and aftermost square frame should be of the same thickness as that on the flat of the bottom; but it may be reduced in thickness 1-6th towards the hoodings of the stem and stern-post. The thick-stuff and wales are the next above the bottom plank; the wales are the thickest part of all the planking, and placed in the way of the load-water line to strengthen the vessel at that place. It was formerly the practice to place the wales with their lower edge about one-half the height of the midship-frame from the upper part of the keel or rabbet, *i. e.* near the heads of the second futtocks, which was thought to add considerably to the strength of the vessel. The upper-works and deck-binding was thus kept lighter, and the vessels being built on a broader proportion, possessed greater stability than ships on the modern construction.

The bends or wales, according to the present mode of building, are placed much higher, their lower edge at midships being from 3-5ths to 5-8ths of the height of the midship-frame from the keel to the gunwale above the upper part of the rabbet of the keel. Their breadth or depth is from 1-6th to 2-13ths of the height of the midship-frame, and the

number of strakes from two to six, according to the nature of the materials and size of the vessel; their thickness, once and a half the thickness of the bottom plank. They are generally made of the best materials. The thickness of the projecting planks is tapered off, above and below, to the size of the bottom and top-side, by sometimes one, two, or three strakes: those below are called thick-stuff, or the diminishing work; those above are called the black-strakes.

The top-sides is that part of the planking between the uppermost black-strake and sheer-plank or paint-strake. They are commonly worked narrow, and lined to a parallel breadth of from 5 to 8 inches; their thickness, for vessels employed in the coasting trade, where they are much exposed to strokes or hard rubbing, should be the same as on the side below the thick-work under the wales; but for vessels in other trades, 5-6ths of that thickness is sufficient.

The sheer-planks are the uppermost on all flush-built merchant ships, and should be made of the best and most durable quality of timber, as they are much exposed to rot, and the whole binding of the upper-deck knees has to pass through them. Ships of 200 tons and under have but one of these strakes, as broad as can be conveniently worked; vessels above that tonnage have frequently two strakes; their thickness should be the same as that of the bottom or upper back-strakes, and is commonly 3-4ths or one inch thicker than the top-sides. When there are two strakes, the butts should have a long shifting, with a scarph of 2½ or 3 feet long, in place of a square butt. These two strakes are bolted together edgeways, opposite to the opening between every other timber.

The plank-sheer or covering-board is that plank which lies on its flat, going round all the stanchions, and covering the tops of all the timbers. Its thickness should be the same as the bottom plank. It is bolted through all the timber-heads and stanchions, and downwards to the sheer-plank and water-way.

The planking on the inside of the ship is commonly 1-6th part thinner than the outside, with the exception of the binding-strakes, such as stringers, clamps, &c., which come under and above the beams, the fastenings of which come through some part of the wales or thick plank, above or below, according to the situation of the beams.

The planking of the ceiling is similar to that of the outside, with the difference only of being a little thinner, and that a shake or split in the end of a plank is considered immaterial, provided the timber is of a sound or healthy quality.

On Expanding the Bottom and Upper-works.

The expansion of the bottom and upper-works, for obtaining the situation of the butts of the plank, so that the materials may be placed to the best advantage, may be laid off in the following manner. It is but little practised, particularly by those who are in the line of building small vessels, the materials being light, and of various qualities; but it becomes of very considerable importance in the planking of ships of a large dimension; for by having an account of the length and quality of the timber, the planking of the vessel may be carried on with expedition and advantage as regards the strength of the vessel, and also the saving of materials. Although it is considered of little importance by those who are unacquainted with the method, or too much attached to an

old practice, I shall give some directions for the expansion of the bottom and top-sides on the paper, and likewise for the shifting of the butt, which will be useful in shewing the method of placing them on the planking-board, used in the building-yard, and described in the practical part of this work.

We must observe, however, that there can be no true expansion of the bottom, so as to exhibit the exact form and dimension of the plank, without cutting or dividing it into a number of parts, like the covering of an umbrella, or the surface of a globe, which would require to be slit through every meridian before the true form and dimensions of the surface could be exhibited; at the same time, the expansion of the bottom of a vessel may be laid down in one or two pieces, sufficiently correct to answer the purposes of the practical shipwright.

To expand the Top-sides and Bottom.—First, from your proper draught take the extreme length of the ship, measuring round the extremity of the side from the midship-frame to the stem, and also from that to the stern, in the following manner:—Lay a mould or batten so as to fit fair round by the main-breadth line; fix it down to the paper with weights or pins, so as not to shift easily; take a narrow slip of paper cut straight on the edge, and bend it tight round the outer edge of the mould or batten; then on the lower edge of the slip, with a sharp pencil, mark all the frames and cant-timbers from stem to stern; lay the slip so marked flat down on the paper, and it will give the extended distance betwixt every frame or cant-timber from stem to stern; or, the expanded length and distance between them may be found by marking the frames on the edge of any mould which answers the curve, and rolling it on its edge along the paper, and marking all the spots as they come down. Having obtained the extended length of the top-side and lower-wale, draw in the sheer-draught agreeable to that length; set off the breadth of the planks, and draw them from the lower part of the wales to the top. Having laid down the sheer-draught in this manner, draw another line as far below the lower edge of the keel, and parallel to it, as the length of the whole girth of the midship-frame, from the rabbet of the keel to the top of the work, measuring round the thickness of the plank; then square down the length of the keel, and the spot where the rabbet of the stem begins to take its rise from the straight rabbet; also square down all the frames from the keel of the sheer-draught with the pencil, and mark their characters. Then take the girth of the midship-frame from the bottom of the rabbet to the floor-sirmark in the compasses, and set that distance off from the line which represents the bottom of the rabbet of the keel, upon the line of the midship-frame, and it will be the spot where the second diagonal ribband-line must come through. Also take the girth of all the other frames in the same manner, including the rounding and thickness of the plank; set these on their respective frames—only observe, that when you come near the foremost and aftermost square-frames, in place of setting them square up as in midships, set one point of the compasses in the rabbet-line, and with the other describe a small arc from the square line forward in the fore-body, and afterwards in the after-body, as the position of the frame-lines will incline towards the bow and stern as they recede from midships; then draw a fair line over all the spots, and touching the back of all the curves from the foremost to the aftermost square-frame, which will represent the

diagonal ribband-line to that extent. Next take the distance from the end of the straight line of the rabbet of the keel on the sheer-plan, to the place where the diagonal ribband-line comes to at the rabbet of the stem; set one point of the compasses on the end of the straight rabbet of the keel in the planking-plan, and with the other foot describe an arc forwards and upwards; then, with the length of the diagonal ribband-line from the fore-frame to the hoods, place one point of the compasses on the end of the ribband-line on the fore-frame, and the other will cut the curve described by the length of the hoodings from the straight of the rabbet-line forward, which will be the place where the end of the ribband-line must be drawn to. A regular curve, drawn from the end of the ribband-line at the fore-frame, and corresponding with it, to the point marked by the intersecting curves, will give the extended length betwixt the fore-frame and the stem. On this line, mark the station of all the cant-frames, and draw them from it down to their proper place at the rabbet. In laying off the after-end, in place of keeping the garboard-strake fair with the line of the keel, it will answer better to turn down its after-end, beginning at the aftermost square-frame, to about once and a half its breadth; then with the height of the ribband-line upon the post, taken in the compasses, set one point on the lower corner of the garboard-strake, and with the other describe a curve aftwards and upwards; and with the length of the ribband-line from the aftermost square-frame to the hoods, taken in the compasses, it will reach from the frame to a spot in the curve, drawn from the after-end of the garboard-strake, which will point out the back-raking of the hoods and the end of the ribband-line. Then try the length of the extended ribband-line, with that on the floor-plane of the proper draught, and if it is the same, it may be considered correct. On that line mark all the frames at their extended distances, and draw them down to their place on the rabbet-line, which will shew the position of the frames with respect to the expansion of the bottom from the keel to the bilge. From this you may proceed in the same manner up to the wales; after which, draw in the breadth of all the planks from the wales to the keel. At the same time, this degree of nicety in extending the whole length is unnecessary with merchant ships, as there is commonly so little rounding on the side and bottom between the second foremost and aftermost square-frames. It will be sufficient only to square down all the midship-frames as in the proper sheer-draught, and extend the rounding of the bow and quarter, as shewn in *Plate* XXI.

On the Shifting of the Butts.—By the shifting of the butts is meant, placing the end of one plank past the end of the other, so that the joining of their ends shall be so disposed that the whole of the work on the outside of the vessel may be equally strong, in such a manner that the parts of the ship which are most exposed to strain shall possess the greatest degree of strength. There are two methods of shifting the butts, viz. what is called two-plank shifting and three-plank shifting: The two-plank shifting is commonly used when the materials run rather short, but will make very good work when judiciously managed, and it is sometimes partially applied for one or two strakes only, on ships which are all otherways done with a three-plank shifting; but this is chiefly for the purpose of introducing a shorter or longer set of plank, and the three-plank shifting is again continued.

In placing the butts for a two-plank shifting, that is, to have two planks crossing betwixt the butt that is above and the one below, you must, in planking upward or downward, shift the butts 1-3d of the length of the plank either forward or aftward continually, except on the luff of the bow, where the shifting-off butts are often obliged to be kept shorter or nearer each other, on account of keeping the plank as much as possible clear of snying. However well this way of planking may be performed, it is much inferior to the other, both in strength and appearance; for in whatever direction the butts of the second strake are placed, they will all run in the same way, resembling the steps of a stair, from the bottom of the vessel to the top.

The appearance of two-plank shifting may be greatly avoided in the midship part of the vessel, when the materials will permit, by shifting the butts two or three timbers forward or aft, in place of directly above or below on the same timber. This is frequently practised when the planks vary much in length, and is considered to improve the strength of the work.

When it is intended to have three strakes betwixt the butts before butting again on the same timber or the one next to it, you must divide the length of the plank into four, thus: Supposing the length to be 20 feet, the shiftings would then be 10 feet for what is called the double shift, and 5 feet for the single; then, when the butts of the first strake are placed, and you begin with the single shift, put the butt of the second strake 5 feet forward, and the butt of the third 10 feet, which brings the middle of the third strake right over the butt of the second; then bring the butt of the fourth strake 5 feet aftwards, and the middle of the fifth strake right over the butt of the fourth, which will bring the butts of the fifth strake right over the butts of the first, and three strakes betwixt them; in this case, the 3d, 5th, 7th, &c. will be all double shifts, and the 2d, 4th, 6th, &c. will be single shifts.

When you begin with the double shift, place the butts of the second right over the middle of the first; then go 5 feet forward with the third, 10 feet back with the fourth, and 5 feet farther aft with the fifth, which will be right over the butt of the first. In this case, the 2d, 4th, and 6th will be double shifts, and the 3d, 5th, and 7th, &c. single; so that by knowing the number of strakes to be put on, you may bring the last strake to be either a double or single shift, according as you place the butts of your second strake. In working English plank, or what is called *Top and Butt*, the planks are not of a parallel breadth, but wrought with a broad and narrow end alternately, as represented by *Fig.* 2, *Plate* XXI. in the wales, strakes 24, 25, 26, and 27, every other strake forming a fair seam. As the three figures in the plate referred to exhibit the length of the planks and shift of the butts of a ship of 300 tons, any farther directions here are unnecessary.

On Whole-Moulding.

Whole-Moulding is a method of drawing the rounding part of all the square-frames by a sweep of the same radius, or with a mould formed to answer this purpose, called the *Bend-mould*. This method of moulding was formerly much used for constructing boats or ships which were narrow abaft, and had a considerable round on the side; but it is quite inapplicable to the draught of ships on the present construction. In

whole-moulding, the sheer-draught and floor-plane is laid down in the common way, only that the rising-line is drawn in the same manner as a buttock-line, being a vertical longitudinal section representing the lowest part of the curves by which the bilge and rounding parts of the bottom are formed. The rising-line and lower height of breadth line should run parallel to each other, and be perfectly fair. The bend-mould is made to answer the round of the midship-frame from the lower height of breadth downwards, forming the round of the bilge; from which part it must be perfectly straight, similar to a futtock-mould, only the straight part of the mould is made to extend from the lower part of the curve straight across on a level, in place of pointing to the upper edge of the rabbet of the keel; it is also as long as to reach considerably past the other side of the keel.

The bend-mould being constructed, and laid in the position for drawing the midship-frame, the lower height of breadth is marked on its upper end, and the centre-line of the vessel for every frame on the lower end, which is lying across the keel on a level, and as far above it as the rising of the midship-floor. This mark is drawn across the mould with a square, also the centre-line of all the other frames outside of it, according as the ship diminishes in breadth. The next thing to be provided is called the hollow-mould; it is made nearly in the same form as the other, but applied in a reverse manner. It is made straight for about half of its length, or so as to reach from the keel to the round of the bilge; and towards the other end, it is made to diverge from the straight into a regular curve, so as to form the hollow part of the frames in the runs of the vessel. A square or board is also required, which should be as broad as the siding of the keel, and as long as will take on the greatest rising of the floors, cut perfectly square on the upper end, with the middle-line drawn on it, and the rising of every floor squared across. When the frames are to be laid down by this method, the rising-line and lower height of breadth line being drawn, the base-line, side-lines, and middle-line for the body-plan, may all be erected in the common way. The lower height of breadth line is then taken from the sheer-plan for every frame, and set up from the base-line, and squared across in the body-plan; also the height of the rising-line for each frame, in the same manner.

When every thing is thus prepared, and a frame to be laid down, put the lower or straight part of the bend-mould with its lower edge fair with the rising-line, as drawn across on the body-plan, and the upper end out to the breadth mark, on the lower height of breadth line; the middle-line mark on the mould will then be on the centre-line of the body-plan. Draw round by the outside of the mould; and if the floor is to have no hollow on the lower part, strike a straight line from the back of the round of the bilge to the upper edge of the rabbet, and the frame is finished from the lower height of breadth to the keel; but if you intend to have a hollow in the lower part of the floor, lay on the hollow-mould, with the round side upwards and the straight end out, so as to touch the back of the sweep or bend-mould; shove out the hollow-mould, keeping the upper edge of it fair with the rabbet, until you have the hollow required; draw it in by the upper edge of the mould, and the form of the floor is completed. Then, with the mould in this position, mark the side of the keel or edge of the rabbet on it, and annex the character of the frame.

To draw in the other square-frames in the after-body, begin at the aftermost, and lay the bend-mould right to the rising-line and lower height of breadth, as before; then place the hollow-mould with the round edge upwards and the straight end out, touching the back of the bend-mould; push the lower mould outwards, keeping its upper edge fair with the rabbet, until you have the intended hollow on the lower part of the after frame. Draw round the outside of the bend-mould and upper side of the hollow-mould, and mark the edge of the rabbet on the lower end of the mould,—you will then have the extent of the hollow contained between the midship and aftermost square-frame, by the rounding and distance betwixt the marks on the hollow-mould. This distance between the marks must then be divided by the number of frames, and the spaces betwixt them graduated in proportion to the heights or rising of the frames, as measured from the rising-line, with the number or character of each frame annexed.

The moulds being thus prepared, in laying down any of the frames place the bend-mould to the height and breadth as before directed, with the mark on the hollow-mould for the intended frame laid to the rabbet, and its outer end touching the back of the bend-mould. Draw round by the outside of the upper one and inside of the lower one, and so complete the frame from the main-breadth to the keel. The frames in the fore-body may be drawn in the same manner.

Although the lines for every frame laid down in this way may appear fair, when considered by themselves, they may not produce perfect fair lines in a fore-and-aft direction; but this may be easily corrected by forming some ribband and water-lines, which will be otherwise useful in laying off the cant-timbers and fashion-pieces, and by which the bevellings may be taken. The timbers for all the square-frames may also be moulded in the same way by the bend and hollow-mould, by applying the rising square or board to the bend-mould, and laying the hollow-mould to the proper mark and rising marked on the board.

CHAPTER III.

ON THE PROPERTIES OF THE LINES USED IN FORMING THE BOTTOM AND FAIRING THE TIMBERS OF VESSELS—TABLE OF DIMENSIONS, &c.

We may now presume that the reader is sufficiently acquainted with the nature and application of the different lines used in forming the plans of ships, to enter into a consideration of those which are the most proper for enabling him to judge of the form of the vessel for sailing, and on which he should therefore depend for her performance at sea.

Ships of almost every construction will sail, or be propelled, in the direction of the wind; and there are few but what will sail when it is blowing at right angles to their keel, allowing that their bottoms should be but very indifferently constructed for that purpose. All ships of common construction will make head-way, although the direc-

tion of the wind form an angle of two or three points before the beam, but all with more or less velocity, according as their bottoms are nearer to that form which is best calculated for opening and closing the fluid in the most uniform manner, and whose other ramifications, such as masts, sails, &c. are duly proportioned,—seeing that similar effects are thus produced by the wind on vessels of all the various constructions, and that the difference of their sailing is often much less than the disparity in the form of their bottom might lead us to expect. It will be proper to consider the action of the water as producing the resistance to the vessel, and the lines which lie in the direction of its principal action in passing round her bottom.

Vessels have been built, at the expense of Government, according to plans by different persons, in order to discover the best construction; but when tried, it was found that there was less difference in point of sailing than was expected. Men of science have been completely baffled by these apparent incongruities. In an article published in the Annals of Philosophy, on Naval Improvement, the writer* attributes this to our unacquaintance with the nature of the resistance of non-elastic fluids, which may be the case; but he unfairly concludes that the ablest builder is at present ignorant of the curves best adapted for dividing the water.

If the true action of the fluid on the bottom of ships in motion is but partially understood by the able shipbuilders of this country, it is certainly much to be regretted that the most able mathematicians have been forced to confess that their knowledge on this point is very dubious and confined.

If we consider the various constructions of vessels employed in the naval and mercantile service on the several coasts of Europe, we easily perceive that the lines which have been employed in forming their bottoms are very dissimilar, and that in many vessels they do not lie in the direction on which the fluid must act with its greatest effort in passing from stem to stern when sailing. Yet this does not prove that the ablest builder is at present ignorant of the curves best adapted for dividing the water, by which we may suppose that he is ignorant of the nature and action of the fluid on the bottom of the vessel—its particular shape—and what curves he should depend on for giving this form to the bottom of his vessel, in order that she may sail swiftly through the water. It is certain there is a particular direction in which every particle of water acts with its greatest effort, peculiar to the form of the bottom, and that the line of this direction is nearly the same as that which is employed by many shipbuilders for giving the proper form of the bottom in constructing a vessel; at the same time, the line of direction of the greatest effort of the fluid in passing round the ship differs widely from that on which the form of the bottom for sailing has by many persons been supposed to depend. Shipbuilders are a little divided in their opinions with respect to the properties of the lines commonly used for constructing the bottom, but in general place most dependence on the diagonal ribband-lines for forming and fairing the bottom, and for obtaining the bevellings of the timbers. Some are uncertain of their superiority over the water-lines for forming the bottom for fast sailing—others consider the buttock-lines of importance in forming the bottom. The most prevailing opinion is, that the

* Colonel Beaufoy, F. R. S.

water-lines, as formed by the horizontal sections, are the best adapted to form the bottom for fast sailing, and recommend that these lines have no inward hollow, either forward or abaft, but should be fair uniform curves throughout, approaching as near as possible to the form of the curve of least resistance. So much has this theory been respected in many cases, by those whose experience stood opposed to it, that a vessel built after the old fashion, having a hollow in her water-lines abaft, was considered to be of an improper construction. This opinion has been much supported by many of our naval architects, who affirm that it is founded on scientific principles. Experience, however, and a careful examination of the subject, prove it incorrect. It is the more surprising that persons of ability seem to entertain such erroneous and inconsistent opinions, which cannot account for the effect of constructions so opposite to what they would and do recommend. Philosophers allow that a single fact inconsistent with a theory is sufficient to overturn it, and that a true theory must explain a number of phenomena, and not be absolutely inconsistent with any one.

That the water-line sections are of little service in fairing the timber, or in assisting in carrying on the work, must be well known by every practical shipbuilder; and their properties with respect to the sailing of the vessel will, I trust, be clearly pointed out by the following observations.

It is the principle of fluids to press equally in all directions. It is also known that the line of direction of the greatest effort produced by the fluid upon a resisting body is at right angles to the surface on which it acts.

The bottom and sides of ships are built rounding at both ends, not only in the horizontal, but also in the vertical direction, so that, of the whole part immersed, there is only a small portion of the side which is upright (if the vessels be of French or British build), which in vessels fully built is about 1-3d of the depth to which they are immersed. This 1-3d part of the ship's side will be acted upon by the pressure of the fluid in a water-line or horizontal direction. But when the vessel is sailing, she will have more or less of a rolling or oscillating motion, or be heeled over by the pressure of the sails, and that part of the side which before was vertical, will be inclined more or less; therefore the plane of effort of the fluid will now be inclined. The rolling or pitching motion is continually altering the position and form of the water-lines; hence, in a mathematical point of view, there can be no true horizontal action of the fluid upon the ship when sailing, except at the surface of the water. The particles of the fluid below the surface being acted upon by those above, and these again pressing equally in all directions, in proportion to their depth below the surface, while the body is immersed, the compound vertical force of all these particles is equal to the weight of the vessel. And the weight of the whole volume of water displaced is equal to the weight of the vessel. The surface of the water around the vessel is kept at the common level by the equality of the fluid and the equal pressure of the atmosphere. As no part of the bottom or sides of a vessel, except at the surface of the water, can be acted upon by the pressure of the fluid in a horizontal direction, and as the sides at the surface of the water are the only parts which can be so acted upon, the effect produced in a water-line direction is of small moment in comparison to that produced in the inclined and

diagonal directions, as these are not only deeper under the surface, whereby the pressure is greater, but are more opposed to the sailing motions of the vessel.

That the fairing and constructing of any vessel by the water-lines is of less importance than is generally supposed, is proved by comparing the rates of sailing of vessels built on different constructions. Dutch-built vessels, for example, have their water-lines nearly straight for their whole length, and so suddenly turned at the two ends, that they often form a right angle with the keel. Now, if the action of the fluid is exerted in a horizontal or water-line direction, according to the theory of those gentlemen who are advocates for the water-line contruction, ships built in the Dutch fashion would be almost entirely precluded from sailing; whereas it is well known that some of them sail faster through the water than some of our sharp built vessels. Many of our vessels are built on the water-line construction, to split the water asunder horizontally. The Dutch vessels, from the rounding-under of their bows, run over it, and in place of having the water to divide horizontally as they go forward, they depress it under the bottom. Another convincing proof of the fallacy of the notion is clearly exhibited by the sailing and work on clencher-built vessels, whose outside bottom planks are all made to overlap each other, with the projecting edges downwards, running from stem to stern, nearly parallel to a diagonal ribband-line—the whole of these projections forming more or less acute angles to the plane of the water-lines, beginning at the flattest frame, and continually increasing their angles as they near the bow and stern. Now it is evident, that if the real action of the fluid, in passing round the vessel, is in the line of the horizontal section, clencher-built vessels cannot sail near so fast as carvel-built vessels, which have no such projecting edges on their bottoms, but on the contrary, they must be very inferior, because their motion would be retarded by the action of the fluid upon the projecting edges of the plank in the bow, and by a quantity of eddy or dead-water carried along and clinging to the projections of the plank in the after-run. Farther, these projections would much increase the friction, even although they were carried round in the direction of the water-lines. As the line of direction of the projecting edges of the planks of clencher-built vessels differs so widely from that which is so highly recommended by many of our scientific shipbuilders, I have no doubt that if any clencher-built vessel were proposed for fast sailing, and if no vessels of that description had ever been seen or heard of before, she would be condemned without being allowed a fair trial. But long experience has proved beyond doubt, that a properly built clencher-vessel is nothing inferior to the best carvel-built vessels in point of sailing, although the bottom of the latter is apparently free from every obstructing part, and perfectly smooth.

In the paper to which we have already referred, the writer, when alluding to clencher built vessels, says that "vessels so constructed excel in sailing such as are carvel-made, and that this superiority will obtain, so long as the resistance of water to curved lines shall be involved in obscurity." However, it is evident that if a clencher-built vessel naturally takes a particular form, it would be an easy matter for us to determine that form in every possible direction, and then build a carvel vessel to the same, so that there would be no superiority in form of the one over the other; and if, after this,

the clencher-built vessel still shewed a superiority in sailing, the advantage is certainly not to be attributed to the resistance to the curve lines, these being the same in both, but must be traced to some advantage which the projections of the plank confer upon the clencher-built vessel, or to the superior degree of resilence which she is likely to possess.

The projections may confer an advantage in preventing the rolling, or the scending and pitching. If you raise a body out of the water and let it fall, it will have acquired a momentum which will cause it to sink below its common line of floatation; this again will increase the upward pressure of the fluid, and cause it to exceed the actual weight of the vessel (supposing it a vessel); she will then be raised up, bringing her load-water line above the surface of the water; after which, she will descend beyond it again, and so on continue to rise and fall for a little time, until the momentum of these forces is at last destroyed, and she will again settle at her proper depth of immersion. Now, if upon the bottom of the vessel projections are made, these will destroy the first scend by offering a greater resistance; the vessel will therefore go more steadily along in a sea-way, which is perhaps the advantage which is gained by the projections of the edges of the planks of the clencher-built vessel. Before, however, we advance upon clencher-built vessels as being so much superior in sailing to those that are carvel-built, we should be certain that a fair trial has been made. In working the plank of the clencher-built vessel, they naturally throw her bottom into a very fine sharp form for sailing.

It is observed, that all bodies equal in weight with water, when they come in contact with the bow of the vessel when sailing, are carried downwards under the bottom, in a diagonal direction, with more or less of an inclined course, according to the form of the bow and entrance of the vessel at the place of contact. In raking-out bows, bodies considerably lighter than water are carried down in a similar manner, in place of being thrown off at the side in a horizontal direction.

All vessels have a rake of the bow, more or less; also, the transverse section of the bow rakes outwards from the fore part of the keel or stem, in form of an inverted cone. Now in this case the resultant of the compound pressures of the fluid will be a mean between the vertical and horizontal pressures, and will be nearly in the direction of the plane of the diagonal ribband. If *Fig.* 122, *Plate* VI. represent the midship section of a vessel immersed to the line D, the surface water G D, which presses on the side A *e*, which is nearly perpendicular, presses horizontally, or in the water-line direction. A particle of water, moving in the direction G D, attacks the side at the point D, and is reflected back in the same plane D G. If we consider a particle to move in the direction *h i*, and strike the inclined part of the bottom *e g* in the point *i*, then in place of being thrown back in the direction *i h*, it would tend to take that of *i j*, the angle of reflection being always equal to the angle of incidence; however, it cannot take the direction *i j*, because there is at the same time a particle pressing in the direction *j i*. The force *j i* tends to lift the ship, and the other *h i* to push her in its direction. Now the resultant of these forces is represented by the line *k i*, perpendicular to the surface *e g*. Again, the sections of the vessel vary in form as they go forward and aft, the plane of the

action of the fluid at the same distance from the keel will vary between the direction *k i* and the horizontal line *h i*, which will be the plane of the direction of the greatest effort of the fluid when it leaves the vessel at the stern-post. The line *p i* may be taken to represent the direction of the action of the fluid upon one of the after-body frames, as frame 6. Accordingly we find, after duly considering the subject, that the true line of direction of the greatest effort of the fluid upon the vessel in passing from the stem to the stern, and *vice versa*, is a twisted diagonal plane, analogous to the plane of the common diagonal ribbands, which accounts for the small resistance which the Dutch-built vessels suffer in passing over the fluid, in comparison to what they would suffer if the action of the water were wholly exerted in the plane of the water-lines, and shews that the greatest action of the fluid, in passing round the clencher-built vessel, is exerted in the diagonal direction, whereby the particles, in place of crossing the edges of the plank, are naturally carried down round the bottom of the vessel, parallel to their fore-and-aft planes; therefore the projections on the bottom of clencher-built vessels do not create any resistance, farther than what is caused by a very small increase of the friction, as compared to that of a carvel-built vessel of the same size and form of bottom. But it must be observed that the water-lines and ribband-lines on any correct plan are affected alike, by altering any of them. Thus if the vessel be made sharper on the water-lines, she will be sharper on the ribband-line at the same place, and *vice versa;* at the same time, the water-lines may be very fair, and have a fine appearance, yet the ribband-lines may be very unfair, and have a bad form for dividing the water. If the water-lines have no inward hollow as they approach the post, the ribband-lines abaft will, to correspond, be too full and unfair, unless to take the hollow out of the water-lines, the vessel be cut away, and made quite flat about the middle of her run. And considering the proper action of the water, which is nearly in the direction of the ribband-line, such a vessel can have little chance of sailing fast, or steering well.

It is generally found, that vessels with full straight water-lines abaft, seldom steer well, such vessels generally requiring false stern-posts stuck on to lengthen out the run, and bring the water more uniformly to the rudder. There are few vessels built with more hollow in the after-run than the smacks which sail between Leith and London, which vessels answer their helms uncommonly well, and in general are the fastest in the coasting trade.

In Emerson's Mechanics, we find the following reference to Marine Architecture :—

" Because the figure of a ship is the cause of her going well or ill, and of making more or less way through the water, I shall here give the construction of the fore part of a vessel that will move through the water with the least possible resistance.

" Let D *d* A *c* C (*Fig.* 123, *Plate* VI.) be the water-line or horizontal section of the water and hull of a ship; A B = 30 feet, C D the greatest breadth = 20 feet, B C = 10, A *e* E the stem and part of the keel; then the following table shews the length of every ordinate *a b c*, taken at the distance A *b*, or 1, 2, 3, 4, 5, 6, &c. feet from A, by which the curve A *c* C is determined :—

Length of A B in Feet.	Length of $b c$ in Feet.	Length of A B in Feet.	Length of $b c$ in Feet.	Length of A B in Feet.	Length of $b c$ in Feet.
1	0.90	11	4.87	21	7.73
2	1.48	12	5.18	22	7.99
3	1.96	13	5.48	23	8.25
4	2.39	14	5.78	24	8.51
5	2.79	15	6.07	25	8.76
6	3.17	16	6.36	26	9.01
7	3.54	17	6.64	27	9.26
8	3.89	18	6.92	28	9.51
9	4.22	19	7.19	29	9.76
10	4.55	20	7.46	30	10.00

" The curve A *e* E which the stem and keel make, must be the same curve as A *c* C: If the depth B E is supposed equal to B C and the ordinates *b e*, B E must also be perpendicular to A B; but if the depth B E be taken greater or less than B C, then the ordinates must be taken greater or less in proportion. Again, if C D E be the section of the ship, made perpendicular to the axis A B or horizontal plane C D, and *c e d* be any other section parallel to it, then whatever the curve C E D is, all the sections C *e d* must be similar to it. If a ship is to be built either greater or less than this, then it is only taking a greater or less length instead of a foot, and dividing it decimally, and using it instead of a foot to measure off the lengths, as in the table.

" Likewise, if it was required to have the breadth to be greater or less than is here assigned, whilst the length remains the same, then it is only taking a proportionally greater or less line instead of a foot, and setting off the ordinates *b c* by that; and thus the requisites may be altered at pleasure, still retaining the general construction.

" If any ship-carpenter thinks fit to build a ship according to this model, it will be found to move faster through the water than any other ship of the same length, breadth, and depth, and of a different form. The form of the curve is truly represented by the curve A *c* C; but it must be observed, that the curve at C, the broadest part, is not perpendicular to the ordinate C B, but makes an angle of about 70 degrees. To avoid this, it will be proper to produce A B a little farther, and turn the side A C at C round in a curve as quick as possible; or else make the 2 and 3 last ordinates something less than in the table, that the part of the curve at C may be in a parallelism with A B, as it ought, because C is the broadest part of the ship.

" But though the form here given is the most proper for sailing fast, yet perhaps it may not be so commodious as the common form, upon other accounts, as for the stowage of goods, &c. Yet privateers, and ships of war made to pursue the enemy, ought to be built as near this form as they can conveniently be; for it is a matter of great moment, either to have it in our power to come up with a ship we are able to take, or else to fly and escape from one of superior force.

" That a ship may steer well, the water ought to come freely and directly to the rudder; and therefore she must not be too short from the midships to the stern, and towards the stern she must rise well, and be built very thin below, lessening gradually to the stern-post."

The form recommended by Mr. Emerson, however advantageous for moving easily

through the water, cannot, as he anticipated, be fully adapted, at the same time for steam-boats, that are propelled by a force independent of the wind on the sails; his ideas may be carried much farther than has yet been attempted, and probably would be attended with a good effect.

It follows, from what has been said on the pressure and action of the water in passing round the bottom, and on the sailing of vessels of various constructions, that the ribband-lines are the most important in the formation of the bottom; and therefore, in forming the draught of a vessel, particular attention should be paid to make them perfectly fair from stem to stern, as the water will act with its greatest effort in their direction, in passing round the bottom when sailing. It is a well-known law in hydrostatics, that fluids exert their greatest effort at right angles to the surfaces on which they act; and on this principle, our former observations may be still farther illustrated.

Suppose a particle of water to strike the bow of a vessel, when sailing, on the side of the stem at the height at the first or second diagonal, as at the point *a*, (*see Body-plan, Plate* XXIII.) a little above the second diagonal. Now, the moment it touches the bow, it is thrown down towards the diagonal more or less; for as it leaves the stem, it is resisted by the sloping-out of the bow, and it will therefore meet frame R at the point *b*. It will then leave frame R in a perpendicular direction, and meet frame Q in the point *c*; it will leave frame Q at right angles, and proceeding down round the bow, in the direction of the arrow, meet frame P at *d*. It will again be directed from P to O in the line *d e*; and so on, continuing to leave the one frame and meet the next in a direction always at right angles to each; and having passed the midship-frame, it will again rise across the after-body frames at right angles, until it meet the stern-post in a horizontal direction. Now, if we find the termination of this line in the floor-plane in the same manner as a diagonal ribband, and take the distance from the centre-line, to where the water-curve (which it may be called, in contradistinction to the water and ribband-lines) cuts the first frame, and set that off from the centre-line of the floor-plane upon its respective frame; in like manner, transfer the intersection of all the frames in the fore and after bodies in the body-plan to their respective frames in the floor-plane, and through these spots draw the curve in the floor-plane, we shall have the dotted curve on which the arrows are drawn, which shews the direction of the water in passing from stem to stern, and which, it will be observed, approaches very near to the fair and beautiful curve of the second diagonal ribband-line, as drawn in the floor-plane of the ship.

Many of the great connoisseurs in the art have been deceived in their ideas of the action and direction of the fluid in passing round the bottom of a vessel when sailing or lying at anchor in a current; consequently it has been much recommended to have no inward hollow in the water-lines near the stern, but that these lines should be formed to the curve of least resistance. However, I trust it has been clearly shewn that the grand object consists in approximating the form of the vessel in the ribband-line direction to that curve. It will be found, that the principal ribband-lines in the plans of the vessels given with this work, are as near to this form as the other circumstances which must regulate the shape of the bottom will possibly admit; and the known good

properties and sailing of these vessels prove the soundness of the principles on which they are constructed. The first, second, and third ribband-lines, and the parts of the other ribband-lines which come under water when the vessel is loaded, are made as fair as possible; but as a necessary consequence, the water-lines have a small hollow towards the stern-post, which, in place of being a disadvantage, as is generally supposed, allows the water to glide more smoothly along in closing behind the vessel, and this brings its direction more in the parallelism of her motion, whereby it will act uniformly on the rudder, and improve the steering. When the water-lines are made straight, or with a convex curve, near the stern-post, the ribband-lines must be by far too full and suddenly rounded, and cause eddy-water, which will in a more or less degree retard the velocity of the vessel and destroy the action of the rudder; also the water, when coming together to close up the cavity which has been formed by the body of the vessel, will meet at each side of the rudder with a great impulse, and render the steering heavy and dangerous to the person at the tiller, which is quite the reverse of what is the case when it is brought smoothly along the sides of the rudder by the inverted curve of the lines near the stern-post.

No part of the bottom of a ship is acted upon by the resistance of the water in a direction exactly opposite to her course; but every part of the fore-body of the ship under water is acted upon obliquely, making her resistance increase as the square of the velocity multiplied by the squares of the sines of the angles of incidence, multiplied by the surface of the fore-body exposed to the action of the fluid, or more properly acting upon it, and exposed to the re-action of the fluid.

The principal action of the fluid in passing under the fore part of the bottom of the ship towards the midship-frame is naturally guided by the form of the bow and entrance in the direction of the diagonal ribband-lines, and its whole effort to resist the ship depending chiefly upon the curving and tapering of these lines, or of the bow in their direction, we cannot too strongly recommend to the young shipbuilder, that the greatest care should be taken that these lines are properly constructed, and quite fair from the stem to the midship-frame, where the action of the ship upon the fluid with respect to her sailing must cease.

From the midship-frame aftwards, there can be no such action of the ship upon the fluid while she is sailing forward, but a voluntary action of the fluid on the ship, produced by the effect of the gravitation of the water, which causes the particles to rush into the hollow which the ship is continually making as she moves forward. Therefore every particle, the moment it passes the midship-frame, in place of being acted upon by the ship, acts upon the ship, and so continues until it leaves her at the stern-post; for every particle being acted upon by the surrounding particles, the water will close again upon the ship by the mutual pressures of the particles upon one another, and produce the greatest effort upon the ship in a perpendicular direction to their points of contact.

On the fore-body, the effort of the water is increased as the squares of the velocity; and on the after-body, it is diminished in the same proportion. The diminution of pressure on the stern-end, by the ship moving forward, is called the *minus-pressure.*

Thus, if a ship is sailing at the rate of 11 miles per hour (about 16 feet 1 inch per second), which is the velocity of a falling body at the surface of the earth, it is the utmost velocity produced by the force of gravity on the water; this is therefore the velocity with which it fills up the hollow made by the ship.

As the stern pressure is always diminished with the velocity of the ship through the water, it is evident that when the velocity of the vessel is very considerable, she must sink down by the stern, in order to present an increased surface for the reduced pressure of the fluid to act on, as she must still be supported by its upward pressure; and hence the cause why fast sailing vessels, when strongly impelled by the wind, settle down so much by the stern. All vessels that are narrow on the transom, and have lean buttocks, settle down by the stern when sailing fast, many even to such an extent as to become dangerous. Some have actually gone down by the stern. However, this dangerous defect may be prevented to a great extent by making the vessel of a proper breadth and fulness on the transom and buttocks, so that when she settles a little by the stern, an additional bearing will be presented to the vertical pressure of the water, and increase the buoyance of her after end. She should not be too low, above water, abaft. Small vessels particularly should have a sufficient sheer, and not be run straight abaft, which is often done by those builders who sacrifice safety and comfort to appearance.

If the bottom of a vessel rise very quick upwards after passing the midship-frame, the vertical pressure has less power to support the after-body of that vessel, than if her bottom were continued farther aft, and rose up gradually from the midship-frame; because she will lose support abaft from the rapid increase of the minus-pressure when sailing fast through the water. In every case of a vessel sailing through the water, the centre of immersion will shift aft from its former position when lying at rest, and the angle of her inclination by the stern will always be such that the vertical line passing up through the centre of support (or displacement) will pass through the centre of gravity of the vessel.

If all the vertical longitudinal sections (as buttock-lines) of a ship were segments of a circle, less velocity through the water would cause her to settle down by the stern; for if we conceive the velocity to be continually increasing, the re-action of the fluid on the fore end will also increase, while at the same time the minus-pressure will increase, *i. e.* the support which the stern half of the vessel receives from the upward pressure of the fluid will be continually decreasing by her leaving the water abaft; hence the vessel is only prevented from turning completely round on her centre of gravity by the wind in the sails on the mast, which act as a lever in keeping her bow down, and preventing her from settling so much by the stern.

From these observations we see the propriety of carrying the bottom of the vessel well aft, and giving a sufficient bearance on the buttock, by which the balance of the bottom is preserved, and many important advantages gained.

M. Boguer has demonstrated, that in order that the ship may be in perfect equilibrio, and have no tendency to run deeper into the water with her bow, or rise out of it and sink with her stern when sailing fast, the main direction of the whole impulse of the wind on the sails must pass through a certain point in the mast, where it is cut by the

line of the direction of the mean impulse of the fluid on the raking part of the bow. Thus let A B (*Plate* VII. *Fig*. 124) be the line of floatation, C D the direction of the opposing fluid, and D C that of the ship. Now, owing to the raking-out of the bow, the resistance of the water will tend to raise it up in the direction C E; therefore let the lines C D and C E represent the measure and direction of these forces. Then, opposed to C D, is the power of the wind on the sails in the direction V E, and opposed to C E is the weight of the ship. Now the diagonal C V is the resultant of these resisting forces, and according to the particular form of the bow it is the direction of mean resistance. Thus if the mean direction of the action of the sails pass through the mast D K, where it is cut by the line V E, the ship will be in perfect equilibrium, and will rise and fall with the sea in a parallel direction. The point V is called by M. Bouguer, point *velique*.

These considerations are mere theory, and never have nor can be attested by experiment on a proper ship; however, the sinking of the stern of the vessel, when sailing very fast, is certainly accounted for by the diminishing action of fluid upon the stern or after-body, as the velocity is increasing, and the resisting force increasing on the fore-body, hereby the reaction of the fluid is tending to increase the support of the fore-body, by which the point *velique* is raised above the centre of direction of the impulse of the wind.

I shall now conclude this subject with the following practical remarks:—The run of every vessel should be considerably longer than the entrance, for the following reason, that water may be opened with any degree of velocity, but it cannot be closed again by any other power than the natural effect of gravity; therefore a sufficient time and space must be allowed for that operation, according to the velocity of the ship. Hence the reason of making the run longer than the entrance, or the part abaft the flat-frame longer than the part before it, according also to the diminution of the action of the fluid upon the stern-half of the vessel when she is sailing fast through the water. The rules given at page 181, for placing and forming the balance and adjusting frames, have been founded on a due consideration of the above theories, and, while consistent with theory, they will also be found to answer in practice.

In constructing a vessel, the greatest possible attention should be paid to the properly forming and fairing those lines which lie nearest in the direction on which the fluid is known to act with its greatest effort. All sea-going vessels should have a good bearance about the buttocks, however sharp they may be in the lower part of the run. Sharp bottomed vessels intended for fast sailing are very often all cut away about the buttocks, which is the very reverse of what should be the case, and consequently these vessels are very dangerous to scud or run with in a gale of wind, and are often under the necessity of lying to, when vessels of even a less size, but of a better construction about the buttock, will be running with safety. These badly constructed vessels are often the work of inexperienced shipbuilders, who endeavour to form what they call *a handsome quarter*! ! by cutting the buttocks away, without considering that they are thereby depriving the vessel of a good property, that of scudding in a heavy sea, and conferring its opposite.

These defects in the construction of a vessel may, however, be considerably abated by the good management of an experienced commander, after making a few passages in the vessel; for although he cannot entirely remove them, yet by properly stowing the cargo of such vessels, shifting the mast, and setting the sails to their most advantageous position, a material improvement on the performance of the vessel at sea may be effected.

From a rigid mathematical investigation, it appears that water will not act upon a moving body in the simple proportion of its depth, or in any other which we are aware of; and hence the difficulty of determining the proper trim that will promote the greatest velocity of any vessel.

A vessel may be in the best possible trim for sailing with a five-knot breeze, and yet this may be a very bad one for sailing with an eight-knot breeze, and *vice versa.*

It has often been observed, that two ships sailing nearly alike with a moderate breeze were differently affected by their trim; when the wind increased, the one being found to leave the other, when she which was left behind, by shifting some parts of the cargo, or heavy things on deck from one part to another, would often again come up with the other. Notwithstanding these alterations of the trim, according to the strength of the wind or height of the waves, a farther alteration is often required in the same ship, in proportion to the depth to which she is loaded, or any alterations that are made on the rake of the masts. From all such and similar circumstances, no shipbuilder or mariner whatever can at once point out the precise trim of a vessel; but the steady attention of the captains and mates, and experiments made by them in stowing the cargo and at sea, will alone enable them to trim their vessel to the best possible advantage.

Notwithstanding all the theory and experience we possess, it is not expected that a perfect model can be produced; for when we candidly consider the many difficulties with which the subject is loaded, such as the various circumstances in which vessels at sea are placed, the irregular motions to which they are subjected by the action of the wind and waves, and the different depths to which they are loaded, and also take into account our superficial knowledge of the *nature* and *action* of fluids,—it becomes rather a matter of astonishment that so much has already been effected in the improvement of the science, than that much yet remains to be done towards bringing this noble art to perfection.

TABLE of Dimensions and Scantlings, and Specification of the Materials for the Building Contract of Eight Vessels.

Specification of different parts, qualities of Materials, &c.	*Dimensions in Feet, Inches, and Eighth Parts, &c.*							
Denomination, Tonnage of each	*Ship,* 603.	*Ship,* 406.	*Ship,* 347.	*Brig,* 303.	*Brig,* 206.	*Schooner,* 151.	*Smack,* 174.	*Sloop,* 62.
	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.
Dimensions of the Hull.								
Length of Keel, from the after-side of the stern-post to the fore part,	106 0	96 5	89 0	84 6	75 0	64 0	65 2	44 0
Fore-rake of the Stem,	12 0	11 7	11 0	10 5	8 6	8 5	8 0	6 0
Length for tonnage,	117 2	108 0	100 0	94 11	83 6	72 5	73 2	50 0
Length on the Main-deck, from the rabbet of hoods at the hawse-holes to the after-side of the stern-post at the deck,	120 0	109 8	98 0	97 0	89 0	73 3	77 5	53 0
Length over all, from the after-side of the taff-rail to the fore part of the figure, or main-stem, in those that have not a head, &c.	139 9	131 7	120 0	115 7	102 6	87 9	82 6	56 0
Breadth of frame,	30 6	28 3½	26 4	26 7	23 0	21 8	23 0	16 9
Breadth for tonnage,	31 0	28 9½	26 10	27 1	23 6	22 2	23 6	17 2
Depth of Hold, from the under side of the main-deck to the ceiling-plank next the limber-boards,	22 0	20 2	19 0	18 7	15 5	13 6	12 6	9 5
Height of the wing-transom, from the upper edge of the keel,	19 4	17 7	15 10	15 7	13 7	12 3	11 8	8 4
Dimensions of the Materials, &c.								
Main Keel—Scotch beech or English elm, sided	0 13½	0 12½	0 12¼	0 12	0 11½	0 11	0 10½	0 9
To be moulded (throughout the whole length),	0 14	0 14	0 14	0 14	0 14	0 13	0 13	0 11
And to be in pieces not more than	three	three	three	three	three	three	two	two
The length of the scarphs to be	5 5	5 5	5 5	5 0	4 0½	4 6	4 0	3 0
Each scarph to be tabled and bolted with *—— bolts, in number	eight	eight	eight	eight	eight	eight	six	six
in diameter	0 1	0 1	0 1	0 0⅞	0 0⅞	0 0¾	0 0¾	0 0¾
False Keel—Of English elm, and to be deep,	0 6	0 6	0 5	0 5	0 4	0 4	0 4	
And to be bolted to the main keel with a —— bolt every two feet; the bolts to be in diameter	0 0¾	0 0¾	0 0¾	0 0¾	0 0¾		0 0⅝	
Main Stem—British Oak, to be sided	0 13	0 12½	0 12	0 12	0 11	0 10½	0 10	0 8
And moulded	0 15	0 15	0 15	0 14	0 14	0 14	0 12	0 9
To be in number of pieces,	three	three	three	two	two	two	two	one
And the scarphs to be in length	3 9	3 9	3 6	3 6	3 6	3 2	2 10	1 10
Secured with —— bolts, in number	six	six	six	six	six	six	five	four
And in diameter	0 0⅞	0 0⅞	0 0¾	0 0¾	0 0¾	0 0¾	0 0⅝	0 0⅝
The foot of the main-stem to be boxed into the the keel, three inches below the rabbet (as shewn in the plan), and to be bolted with —— bolts, in number	six	six	six	five	five	five	four	three
in diameter	0 0⅞	0 0⅞	0 0¾	0 0¾	0 0¾	0 0¾	0 0⅝	0 0⅝
Apron and Stomach-piece—British Oak, to be sided the same as the stem, and moulded to come fair with the inside planking, fastened to the stem at every 20 inches with bolts, in diameter	0 1⅛	0 1⅛	0 1	0 1	0 0⅞	0 0⅞	0 0¾	0 0¾
Stern-post—British oak; to be in one piece from the keel to the top—								
To be moulded at the top,	0 14	0 14	0 13	0 12	0 11	0 10¾	0 10	0 8½
Ditto at the keel,	0 26	0 25	0 24	0 23	0 21	0 19	0 17	0 14
And to be sided	0 13	0 12½	0 12	0 11½	0 11	0 10½	0 9½	0 8½
Inner-post—Best quality of British oak, to reach from the keel to the wing-transom.	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0

* All these blanks are to be filled in with the word "Copper" or "Iron," according as the ship is to be either copper or iron-fastened.

Specification of different parts, qualities of Materials, &c.	*Dimensions in Feet, Inches, and Eighth Parts, &c.*															
Denomination. / Tonnage of each.	*Ship*, 503.		*Ship*, 400.		*Ship*, 347.		*Brig*, 303.		*Brig*, 205.		*Schooner*, 151.		*Smack*, 174.		*Sloop*, 62.	
	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.
Dead-wood—All the dead-woods to be of oak, of sufficient length to cover the scarph of the after-keel, and height for stepping the cant-timbers.																
Berth and space of the floors	0	14	0	14	0	13½	0	13	0	12½	0	12	0	11	0	9
Floor-timbers to be of oak, sided	0	13	0	13	0	12½	0	12	0	11	0	11¾	0	10	0	8½
Moulded at the keel . . .	0	15	0	14½	0	13½	0	13	0	12	0	11½	0	10	0	8½
Ditto at the sir-mark . . .	0	11½	0	11	0	10¾	0	10½	0	10	0	9½	0	8	0	6½
First Futtocks to be of * ———— sided . .	0	12	0	11¾	0	11½	0	11	0	10½	0	9½	0	8½	0	7
Ditto, moulded, to answer the size of the floor at the sir-mark, and be regularly tapered from that upwards, to the proper size at the main-gunwale,	0	6	0	5½	0	5¼	0	5	0	4¾	0	4½	0	4¼	0	3¾
The timbers to be tapered the siding way, from the bilge upwards, from the breadth of the first futtock to the size given at the main-gunwale,	0	10	0	10	0	9½	0	9	0	8½	0	8½	0	8½	0	7
And no shifting of the timber to be less than .	5	0	4	9	4	6	4	6	4	3	4	4	4	4	3	2
The top-timbers for . { number of feet in the middle of the vessel, }											40	0	40	0	20	0
To reach from the heads of the first futtock to the gunwale.																
The floors to be bolted with ——— bolts, in diameter	0	1	0	1¼	0	1¼	0	1¼	0	1⅛	0	1⅛	0	1⅛	0	0⅞
Frames—Every other floor to be framed, and the said frame-timbers to be bolted together with two bolts of ——— on each side of the joint, and the bolts to be in diameter	0	1⅛	0	1⅛	0	1	0	1	0	0⅞	0	0⅞	0	0⅞	0	0⅝
Knight-head Timbers, of British oak, to be square at the head, ...	0	11	0	10½	0	10½	0	10	0	9	0	8½	0	8½	0	6½
Hawse-Pieces, in number on each side, . .	three		three		three		two		two		two		two		one	
Ditto, in breadth, ...	0	16	0	15½	0	14½	0	14	0	14	0	14	0	14	0	14
And moulded the same thickness as the knight-head.																
Particulars of the Frame-Timbers—All the floor-heads, and heels of the second futtocks, properly fixed with cross chocks, in length	3	0	3	0	3	0	3	0	2	8	2	8	2	8	2	0
And the points of said chocks let into the floor-heads and second futtocks, *number of inches* . .	0	2	0	2	0	1½	0	1½	0	1½	0	1½	0	1½	0	1
And all the joints of the different timbers which compose the frame of the vessel, to be done in the same manner.																
No floor or first futtock-head to be moulded thinner than 1-3d of their proper thickness; and all the short top-timbers to be scarphed to the heads of the second futtock; the said scarphs to be in length	1	8	1	8	1	6	1	6	1	3	1	3	1	3	1	0
Points of the scarphs in thickness	0	2	0	2	0	2	0	1½	0	1½	0	1½	0	1½	0	1
And fastened with two bolts, in diameter . .	0	0¾	0	0¾	0	0⅝	0	0⅝	0	0⅝	0	0⅝	0	0⅝	0	0½
No chocks must be required higher than the heads of the first futtocks.																
The whole of the timber above the first futtock-head, afore and aft, generally of British oak, with the exception of the second futtocks, which may be white Hamburgh oak amidships. The timber should be all properly squared, and free from sap, having no less at any place than 2-3ds of the proper breadth of the timber clear of every defect.																
Transoms—British oak: Wing-transom to be sided and moulded as strong as the midship floors. The berth and space of the transoms the same as the	0	13	0	13	0	12½	0	12½	0	11	0	10½	0	10½	0	8½

* All such blanks to be filled in with the word English, or other oaks, as may be agreed on by the parties.

Specification of different parts, qualities of Materials, &c.	*Dimensions in Feet, Inches, and Eighth Parts, &c.*															
Denomination, — Tonnage of each, —	*Ship*, 503.		*Ship*, 400.		*Ship*, 347.		*Brig*, 303.		*Brig*, 205.		*Schooner*, 161.		*Smack*, 174.		*Sloop*, 62.	
	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.
floors. All the transoms, with the exception of the wing-transom, to be sided	0	10	0	10	0	9½	0	9½	0	9	0	9	0	9	0	7
And moulded as strong as the midship floors																
To be all bolted with copper bolts, to pass through all, and be clenched on the after-side of the main stern-post, the wing-transom to have two bolts,	0	1⅛	0	1⅛	0	1⅛	0	1	0	0⅞	0	0⅞	0	0⅞	0	0¾
The bolts to be in diameter	0	1¼	0	1¼	0	1¼	0	1¼	0	1⅛	0	1	0	1	0	0⅞
Heel-Knee—British oak; to be of a proper size; to have—number of bolts through the stern-post,	five		five		five		four		four		four		four		three	
Diameter of the bolts,	0	1¼	0	1⅛	0	1⅛	0	1⅛	0	1	0	1	0	1	0	0⅞
Wing-Transom—To be secured at the ends to the side of the vessel by fore-and-aft knees, either of wood or iron, as may be found most convenient for the accommodation of the cabin.																
Quarter-Timbers—To be in pieces,	two		two		two		two		one		one		one		one	
Moulded and sided square at the foot,	1	0	1	0	0	11	0	10½	0	10½	0	10	0	10	0	9
Ditto at the arch board,	0	11	0	11	0	11	0	9½	0	9½	0	9	0	9	0	8
Ditto at the height of the main-gunwale,	0	9	0	9	0	9	0	8	0	7	0	7	0	7	0	6
Ditto at the taffrail,	0	8¾	0	8	0	8	0	7	0	6¾	0	6¾	0	6¾	0	6
The scarphs to be in length	3	0	3	0	2	6	2	6								
And secured with —— bolts, in number	six		six		six		six									
in diameter	0	0¾	0	0¾	0	0¾	0	0¾								
The quarter-timbers to be secured to the ends of the wing-transom, with upright knees at each end, and to be bolted down to the transom with bolts, in number	four		four		four		four		three		three		three		three	
in diameter	0	0⅞	0	0⅞	0	8⅞	0	0⅞	0	0⅞	0	0⅞	0	0¾	0	0¾
And bolts through the upright arm of the ames size.																
To have a piece of good timber fitted down to the top of the wing-transom betwixt the ends of the upright knees, and against the heels of the timbers in the counter, and said piece to be well bolted down to the transom, through the stern-post and heels of the stern or counter-timbers; also a false transom or beam fitted along the inside of the counter-timbers, as high as can be got for the stern-post, with natching a small portion out of each, and said beam to be secured at the ends to the sides of the vessel by diagonal knees, either of wood or iron, as found most convenient, and said knees well bolted through the side and stern timbers; also all the ends of the bottom plank, which come into the counter, bolted through the said transom; likewise a strong bolt through the stern-post, which, with all the others, must be clenched.																
Cant-Timbers—Every other timber abaft the aftermost floor to be stepped into the dead-wood,	0	2	0	2	0	2	0	2	0	2	0	1½	0	1¾	0	1¼
And secured with two bolts in each—in diameter	0	1¼	0	1⅛	0	1	0	1	0	1	0	1	0	1	0	0¾
And the said bolts to pass through both timbers and dead-wood.																
Every other cant-timber, abaft the aftermost, and before the foremost square frame, to be formed into a regular cant frame.																
Fashion-Timber, in pieces,	two		two		two		one		one		one		one		one	
To be sided	0	9	0	9	0	8	0	8	0	7	0	7	0	7	0	6
To be moulded as large as required.																

Specification of different parts, qualities of Materials, &c.	*Dimensions in Feet, Inches, and Eighth Parts, &c.*							
Denomination,......... Tonnage of each,.......	*Ship,* 503.	*Ship,* 400.	*Ship,* 347.	*Brig,* 303.	*Brig,* 205.	*Schooner,* 151.	*Smack,* 174.	*Sloop,* 62.
	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.
Stern-Timbers, sided at the counter, . .	0 9	0 9	0 8	0 8	0 7	0 7	0 7	0 6
Ditto do. at the top, . .	0 8	0 8	0 7½	0 7	0 7	0 6½	0 6½	0 5
Ditto moulded at the counter, .	0 11	0 10½	0 10	0 9	0 8½	0 8	0 8	0 6
Ditto do. at the top, . .	0 8	0 8	0 7½	0 7	0 6½	0 6½	0 6½	0 5
Outside Plank.								
Bottom Plank—All the bottom plank in midships, up to the* .... thick-stuff under the wales; to be in thickness	0 4	0 3½	0 3	0 3	0 2½	0 2½	0 2½	0 2
Hoodings, ...	0 3	0 3	0 3	0 3	0 3	0 2½	0 2½	0 2
Garboard-Strake—in thickness, . . .	0 4½	0 4	0 3½	0 3½	0 3	0 2½	0 2½	0 2
Bilge-Plank—to have strakes on each side, .	six	five	five	five	four	four	four	three
to be in thickness . . .	0 5	0 5	0 4	0 4	0 4	0 4	0 4	0 3
Thick Strakes under the wales, to have .	three	three	three	two	two	two	two	one
Wales—To be of † .... in thickness .	0 6	0 6	0 5	0 5	0 5	0 5	0 5	0 3
Number of strakes, ...	six	five	five	five	four	four	four	three
Black Strakes—All the plank of the top-sides to be of English oak, to have black strakes .	three	three	three	three	two	two	two	one
In thickness, one next the wales, .	0 5	0 5	0 4	0 4	0 4	0 4	0 4	0 2½
Do. second next the wales, .	0 5	0 4	0 4	0 4	0 3	0 3	0 3	0 2
Do. third next the wales, .	0 4	0 4	0 3	0 3				
Top-Sides—in thickness	0 3	0 3	0 3	0 3	0 2½	0 2½	0 2½	2 0
Paint or Sheer-Strakes—in number . .	two	two	two	two	one	one	one	one
Each in breadth, including the mouldings .	0 9	0 9	0 9	0 8	0 12	0 12	0 11	0 9
And in thickness, ...	0 4	0 4	0 4	0 4	0 3	0 3	0 3	0 2½
The Sheer-strakes to be hook-scarphed.								
The scarphs in length, ...	4 0	4 0	4 0	3 6	3 0	3 0	3 0	2 3
And the scarphs to be bolted edge-ways with —— bolts, in number	three	three	three	three	three	three	three	two
in diameter	0 0¾	0 0¾	0 0¾	0 0¾	0 0¾	0 0¾	0 0⅝	0 0⅝
Shifting of the Butts—All the outside planking to have no less than	6 0	6 0	5 0	5 0	5 0	5 0	5 0	4 0
shifting of the butts, and three strake of plank between each; except on the bow or buttock, where they may occasionally be contracted to but three strake between must be continued.	4 0	4 0	4 0	4 0	4 0	4 0	4 0	3 0
N. B. If foreign plank is used, the midship shifting must extend to	7 6	7 6	7 3	7 0	6 0	5 0	5 0	4 0
The Outside Plank of the poop, forward and aft, to be planed and beaded on the joints, to correspond with the sheer of the bulwarks, and to be in thickness	0 1¾	0 1¾	0 1¾	1 1½	0 1			
Inside Plank of the poops, ditto, ditto.								
Butt-Bolts—All the butts in the bottom to have two —— bolts in each, one of . . .	0 0¾	0 0¾	0 0¾	0 0¾	0 0⅝	0 0⅝	0 0⅝	0 0½
in diameter in the butt timber, and one of in diameter in the timber next the butt, to go through all and be clenched on the ceiling-plank.	0 0⅞	0 0⅞	0 0⅞	0 0⅞	0 0¾	0 0¾	0 0¾	0 0⅝
Extra Bolts—To have a bolt every three feet in each of the bilge-planks, drove through all and clenched; bolts to be copper, and their diameter	0 0⅞	0 0⅞	0 0⅞	0 0⅞	0 0⅞	0 0⅞	0 0¾	0 0⅝
Butt-Bolts in the wales and top-sides—All the butts in the wales and top-sides to be bolted in the same manner as the butts in the batten plank, with the difference only, that the butt-bolts in the top-sides are to be iron.								
After-Hoods Butts—All the butts in the after-hoods in the bottom to have two copper bolts, to								

* This Plank may be filled up with Dantzic Oak, Beech, Memel Fir, or whatever the parties may agree to use for bottom planks.
† Generally filled up with Dantzic Oak.

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After-Hoods Butts—(*continued.*)	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.
pass through all and be clenched where they can be got; the bolts in diameter	0 0⅞	0 0⅞	0 0⅞	0 0⅞	0 0⅞	0 0¾	0 0¾	0 0⅝
Narrow Fore-Hoods—To be single bolted with copper bolts; in diameter	0 0¾	0 0¾	0 0¾	0 0¾	0 0⅝	0 0⅝	0 0⅝	0 0½
Treenails—The treenails to be all of the best English oak; in diameter	0 1⅜	0 1⅜	0 1⅜	0 1⅜	0 1¼	0 1¼	0 1¼	0 1⅛
Inside Work.								
Keelson—To be * .... oak, and to be in heights	three	three	three	two	two	two	two	one
The lower piece sided	0 14	0 13	0 13	0 13	0 13	0 12	0 14	0 10
The upper piece sided	0 13½	0 12½	0 12½	0 12½	0 12½	0 11½	0 13	
The lower piece deep	0 15	0 14	0 14	0 13	0 13	0 13	0 13	0 11
The upper piece deep	0 15	0 14	0 14	0 13	0 13	0 13	0 13	
The keelsons to be of sufficient lengths to bolt both to the stem and heel-knee, and all the scarphs of the keelsons to be in length	8 0	8 0	6 6	6 6	6 6	6 6	6 6	5 6
The scarphs of the lower pieces to be properly secured before the upper pieces are laid on. In the ships, brigs, and schooner, one of the uppermost pieces of the keelson must be of sufficient length, and so placed as to extend under the foot of both the fore and main-mast; likewise all the scarphs must be placed clear of the keel-scarphs and the scarphs of each other. The lower pieces to be stopped down to the floors with with a few small bolts, until the upper pieces are fitted; and the whole is to be bolted through both keelsons, every other floor and keel with copper bolts, in diameter	0 1⅜	0 1⅜	0 1⅜	0 1⅜	0 1¼	0 1¼	0 1⅛	0 1
Ceiling—The ceiling to be all †...... oak; to have two strakes next the limbers in the three ships, and to have only one strake in the others; to be in thickness	0 4	0 4	0 4	0 4	0 3	0 3	0 3	0 2½
These strakes to be bolted down to every floor; bolts to be in diameter	0 0¾	0 0¾	0 0¾	0 0¾	0 0¾	0 0¾	0 0¾	0 0⅝
To have strakes, in number	five	five	five	four	four	four	four	three
,, in breadth	10 or 12	0 11	0 11	0 11	0 11	0 10	0 10	0 9
,, in thickness	0 5	0 5	0 5	0 4	0 4	0 4	0 4	0 3
On each bilge, number to run from stem to stern	three	three	three	two	two	two	two	two
Thick-stuff, at the first futtock-heads, number of strakes	four	four	three	three	two	one	one	one
The middle strake, or the strake right on the joint, to be in breadth	0 10	0 10	0 10	0 10	0 10	0 10	0 12	0 9
in thickness	0 5	0 5	0 5	0 4½	0 4	0 4	0 3½	0 2
And the strakes above and below the one at the joint, to be in thickness	0 4	0 4	0 4	0 4	0 3½	0 3½	0 3½	0 3
Number of strakes to run from stem to stern .	two	two	one	one	one	one	one	one
The others may be reduced to the thickness of the ceiling plank, at distance from stem and stern	14 0	12 0	11 0	10 0	6 0	6 0	5 0	5 0
All these strakes to bolted with —— bolts every two feet throughout the whole length, in diameter	0 0¾	0 0¾	0 0¾	0 0⅝	0 0⅝	0 0⅝	0 0⅝	0 0½
Ceiling from the last-mentioned thick-stuff to the clamps for the 'twixt-deck beams, in thickness	0 3	0 3	0 3	0 3	0 2½	0 2½	0 2½	0 2
Clamps for the 'twixt-deck beams, number of strakes	two	two	two	one	one	one	one	one
Ditto ditto in breadth .	0 12	0 12	0 12	0 12	0 11	0 11	0 11	0 10
Ditto ditto in thickness .	0 5	0 5	0 5	0 5	0 4	0 4	0 4	0 3
To be hook-scarphed, and the length of the scarph to be	5 0	5 0	5 0	5 0	4 6	4 0	3 0	2 0

* Generally the Kelsons are Hamburgh or Dantzic Oak. † Generally English Oak.

Specification of different parts, qualities of Materials, &c.	*Dimensions in Feet, Inches, and Eighth Parts, &c.*							
Denomination,......... Tonnage of each,......	*Ship,* 503.	*Ship,* 400.	*Ship,* 347.	*Brig,* 303.	*Brig,* 205.	*Schooner,* 151.	*Smack,* 174.	*Sloop,* 62.
	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.
Clamps for the hold beams. The scarphs to be bolted edgeways, with—number of bolts in each	five	four	three	three	three	three	two	two
In diameter	0 0⅝	0 0¾	0 0¾	0 0¾	0 0¾	0 0¾	0 0¾	0 0¾
And the clamps to be bolted to every timber with —— bolts, in diameter	0 0⅝	0 0⅞	0 0⅝	0 0⅝	0 0¾	0 0¾	0 0¾	0 0⅝
Breast-hooks—To have breast-hooks, number in all	eight	eight	eight	six	six	five	five	three
The upper one, in length	16 0	16 0	16 0	15 0	14 0	12 0	12 0	9 0
The one under the main-deck, in length . .	16 0	16 0	16 0	15 0	14 0	12 0	12 0	9 0
The former sided	0 11	0 11	0 10½	0 10	0 9	0 9	0 8	0 9
,, moulded	0 12	0 11½	0 11	0 11	0 10	0 10	0 9	0 7
The latter sided	0 14	0 14	0 13½	0 13	0 12	0 12	0 12	0 9
,, moulded	0 15	0 15	0 15	0 14	0 13	0 13	0 13	0 10
All the other hooks to be in length . . .	15 0	15 0	15 0	14 0	14 0	14 0	14 0	8 0
,, to be sided	0 12	0 12	0 12	0 11	0 11	0 11	0 11	0 9
,, to be moulded . . .	0 13	0 13	0 13	0 12	0 12	0 12	0 12	0 10
To be fastened with —— bolts in each arm, in number	ten	ten	ten	ten	eight	eight	eight	five
in diameter	0 1⅛	0 1⅛	0 1	0 1	0 0⅞	0 0⅞	0 0⅞	0 0¾
And each to have one bolt in the throat, to go through and be clenched on the stem.								
The throat bolt, and one in each arm of the main-deck hook, to pass through the length direction of a carling, and be clenched on the aftermost side of the fore beam.								
The hooks below the main-wales to be bolted with copper bolts, in diameter as stated above.								
Principal Hold or 'Twixt-deck Beams—The hold-beams to be of ...... oak, and in number as per plans, with one or two more if found necessary.								
The largest, in number	ten	ten	eight	seven	seven	six		
Which number are to be square	0 13	0 12½	0 12	0 11	0 11	0 12		
in the middle, and moulded at the ends to .	0 9	0 9	0 8	0 7¾	0 7¾	0 7¾		
The others to be diminished in scantling, in proportion to their length and situation. All the hold-beams to be double-kneed, as far as can be got; the midship knees to be sided . .	0 8	0 7½	0 7½	0 7	0 7	0 6		
And moulded on the arms not less than . .	0 9	0 8	0 8	0 8	0 8	0 8		
To be bolted through every timber with —— bolts, in diameter , ...	0 1	0 1	0 0⅞	0 0⅞	0 0⅞	0 0⅞		
And number of bolts in the beam-arm, . .	three	three	three	three	three	three		
Each in diameter	0 0⅞	0 0⅞	0 0¾	0 0¾	0 0¾	0 0¾		
Lower Deck Planks, * .... in thickness, .	0 3	0 3	0 3	0 3	0 2½			
To be double nailed.								
To have two strong carlings on each side of the 'twixt-deck main-hatch, sided	0 7	0 7	0 7	0 7	0 7	0 7		
moulded . . .	0 7	0 7	0 7	0 7	0 7	0 7		
These to be secured to the side and partners of the hatch with iron knees at each end.								
Clamps for the upper-deck beams to be of the same size, and done in the same manner as those for the hold beams.								
Main-Deck Beams, &c.								
The Main-deck Beams to be † .... oak, in number and situation as per plan.								
Number of midship-beams, ...	ten	ten	eight	eight	six	six	four	four
Which number is to be sided	0 11½	0 11½	0 11	0 10½	0 9½	0 9	0 10½	0 8
And moulded in the middle	0 11½	0 10½	0 10½	0 10	0 9	0 8¾	0 10	0 7½

* Yellow Pine, or Dantzic Fir. † English Oak.

Specification of different parts, qualities of Materials, &c.	*Dimensions in Feet, Inches, and Eighth Parts, &c.*							
Denomination,—— Tonnage of each,——	*Ship,* 503.	*Ship,* 406.	*Ship,* 347.	*Brig,* 303.	*Brig,* 205.	*Schooner,* 151.	*Smack,* 174.	*Sloop,* 62.
	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.
Main-deck Beams, &c.—(*continued.*) The others diminished in proportion to their length and situation, and the whole to be double-kneed as far as can be got.								
The Midship-Knees to be sided	0 7½	0 7	0 6¾	0 6¾	0 6	0 5¾	0 6½	0 4½
The knees to be bolted through every timber in the side—bolts in diameter	0 0⅞	0 0⅞	0 0⅞	0 0⅞	0 0¾	0 0¾	0 0¾	0 0⅝
Number of bolts in the beam-arm, . . .	three	three	three	three	three	three	three	two
The whole deck frame to be completely warped with ledges and carlings, and not more than two feet apart, ...								
The Carlings to be sided and moulded . . .	0 5	0 5	0 5	0 5	0 5	0 4½	0 4½	0 4
Ledges square	0 4	0 4	0 4	0 4	0 3½	0 3½	0 3½	0 3
Mast-Partners—Partners of the main and fore-masts, broad, ...	0 12	0 12	0 12	0 11	0 10	0 9	0 12	0 8
deep, ...	0 9	0 9	0 9	0 8½	0 8	0 7	0 10	0 5
Mizen-partners—to be in breadth	0 9	0 9	0 9	0 8				
Ditto, in thickness	0 6	0 6	0 6	0 6				
Stepping-pieces for the Capstan—to be sided	0 14½	0 13⅝	0 13	0 12½	0 11½	0 10½		
In depth the same as the beams to which they are fixed; the ends to be let one inch into the beams, and fastened with two angular bolts through the beam at each end.								
Main-deck Plank—To be Dantzic or Memel fir, in thickness	0 3	0 3	0 3	0 3	0 3	0 3	0 3	0 2
Not to exceed in breadth	0 9	0 9	0 9	0 9	0 9	0 9	0 9	0 8
nor under six; and to be all double nailed.								
The Hatches, Scuttles, &c.—To be situated (and of the same dimensions) as shewn in the plan; the coamings for the main-hatches in height above the deck at the side	0 9	0 9	0 9	0 9	0 9	0 9	0 8	0 7
in thickness . . .	0 6	0 6	0 6	0 6	0 6	0 6	0 6	0 5
All the other coamings in depth and thickness as may be required for the intended trade. All the coamings to be English oak, and to be let down to the beams; the side-carlings of the hatches to be properly chacked into each other, and fastened down with —— bolts, in diameter . . .	0 0¾	0 0¾	0 0¾	0 0¾	0 0¾	0 0¾	0 0¾	0 0⅝
Water-ways—The water-ways English oak; to be in thickness . .	0 6	0 6	0 6	0 6	0 5	0 5	0 5	0 4
in breadth . . .	0 10	0 10	0 10	0 10	0 9	0 9	0 9	0 8
To have oak plank inside the water-ways on each side—Number of strakes, ...	two	two	two	two	two	two	one	one
in breadth	0 10	0 10	0 10	0 9	0 8	0 7½	0 10	0 9
in thickness	0 3½	0 3½	0 3½	0 3	0 3	0 3	0 3	0 2½
These strakes of plank to be fixed down to the beams with two small copper bolts in each strake and beam—bolts in diameter . .	0 0¾	0 0¾	0 0¾	0 0⅝	0 0⅝	0 0⅝	0 0⅝	0 0½
Water-ways to be fastened down in the same manner.								
The above-mentioned strakes and the water-way to be bolted to the side through every other timber with iron where it can be done; the diameter of these bolts to be	0 0⅞	0 0⅞	0 0¾	0 0¾	0 0¾	0 0¾	0 0¾	0 0⅝
Said water-ways to go all round the vessel, both bow and stern.								
Iron Hanging and Staple Standard Knees—To have iron hanging keys for the hold-beams, in number, .	26	24	20	20	16	14	14	six

Specification of different parts, qualities of Materials, &c.	*Dimensions in Feet, Inches, and Eighth Parts, &c.*							
Denomination, Tonnage of each,	*Ship,* 503.	*Ship,* 400.	*Ship,* 347.	*Brig,* 303.	*Brig,* 205.	*Schooner,* 151.	*Smack,* 174.	*Sloop,* 62.
	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.
Iron Hanging Knees—(*continued*),—to be in length on the side-arm	5 0	5 0	5 0	4 6	4 0	4 0	4 0	3 6
on the beam-arm	4 6	4 6	3 6	3 6	3 6	3 3	3 6	3 0
in breadth	0 4½	0 4¼	0 4	0 3¾	0 3¼	0 3	0 3	0 2½
in thickness at the throat	0 3¾	0 3½	0 3¼	0 3	0 3	0 2¾	0 2¾	0 2¼
at the points	0 1¼	0 0⅞	0 0¾	0 0¾	0 0⅝	0 0⅝	0 0⅝	0 0½
Number of bolts in the side-arm,	five	five	five	five	four	four	four	four
Two uppermost, in diameter	0 1⅛	0 1⅛	0 1⅛	0 1	0 1	0 1	0 1	0 0⅞
Number of bolts in the beam-arm,	four	four	four	four	three	three	three	three
Two next the throat, in diameter	0 1⅛	0 1⅛	0 1⅛	0 1	0 1	0 1	0 1	0 0⅞
Diameter of the bolts next the ends, 1-4th smaller	0 0⅞	0 0⅞	0 0⅞	0 0¾	0 0¾	0 0¾	0 0¾	0 0⅝
Staple Standard Iron Knees, in number	16	16	14	eight	eight	eight	six	four
Length of the beam-arms,	4 6	4 6	4 0	3 6	3 6	3 6	3 6	3 0
Thickness at the throat,	0 3¾	0 3½	0 3¼	0 3	0 3	0 3	0 3¼	0 2¼
at the points,	0 1¼	0 1	0 0⅞	0 0⅞	0 0¾	0 0¾	0 0¾	0 0⅝
their breadth,	0 4½	0 4¼	0 4	0 3¾	0 3¼	0 2⅞	0 2¾	0 2¾
These knees to be bolted with the same size of iron, and same proportional number of bolts as the hanging keys mentioned above.								
Other Oak Plank in the Main-deck—To have an oak plank on each side of the main hatchway, for fixing ring-bolts, &c. in thickness	0 4	0 4	4 0	0 4	0 3½	0 3½	0 3½	0 2½
Also to have proper oak chocks and oak plank for fixing the windlass and winch.								
Particulars of the Main-Deck.								
Pawl-bitt—good oak, sided	0 15	0 14	0 13⅜	0 13	0 11⅜	0 10⅝	0 11⅜	0 8¼
moulded	0 16⅞	0 15⅝	0 15⅛	0 14⅝	0 12¾	0 11⅞	0 12⅞	0 9⅜
Windlass—ditto, in diameter	0 20⅝	0 19¼	0 18⅜	0 18	0 16	0 14⅝	0 15¾	0 11½
Windlass-bitts—ditto, sided	0 6⅞	0 6⅝	0 6⅛	0 6	0 5⅜	0 4⅞	0 5¼	0 3¾
Breadth or moulding-way of windlass-bitts,	0 20⅝	0 19¼	0 18⅜	0 8¾	0 16	0 14⅝	0 15¾	0 11½
Spindles, diameter in the round	0 3¼	0 3 9/16	0 3 7/16	0 13⅜	0 3	0 2¾	0 3	0 2 5/16
Windlass to be fitted with patent cast-iron wheel and pawls, with cross-rail and belfry.								
Winch-bitts—oak, sided					0 5	0 5	0 5½	0 4
Beams of the Forecastle—in siding	0 7½	0 7						
in moulding	0 6½	0 6						
Round up the same as the main-deck.								
To be double-kneed as far as can be got, with knees in proportion to the moulding of the beams.								
Deck-plank—to be double nailed, each not broader than	0 8½	0 8½						
and in thickness	0 2½	0 2						
The water-ways on the poop to be of English oak.								
Beams of the Poop abaft—sided	0 7	0 7						
moulded	0 6	0 6						
Round up the same as the main-deck. To be all double-kneed, with knees in proportion to the moulding of the beams; deck plank to be Memel fir; each plank not to be broader than	0 6	0 6						
and in thickness,	0 2¼	0 1¾						
Water-ways—English oak, in thickness,	0 3	0 3						
in breadth	0 7	0 6						
Cat-Heads—of a sufficient length and strength.								
Topsail Sheet Bitts.								
Capstan of sufficient size, with all the necessary parts, &c.								

Specification of different parts, qualities of Materials, &c.	*Dimensions in Feet, Inches, and Eighth Parts, &c.*															
Denomination,—— Tonnage of each,——	*Ship,* 503.		*Ship,* 400.		*Ship,* 347.		*Brig,* 303.		*Brig,* 205.		*Schooner,* 151.		*Smack,* 174.		*Sloop,* 62.	
	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.
Stanchions—for the Main Rail,—																
To be in breadth, at the gunwale, . .			0	7	0	7	0	7	0	6	0	6	0	6	0	5
at the rail, . . .			0	5	0	5	0	5	0	$4\frac{1}{2}$	0	$4\frac{1}{2}$	0	$4\frac{1}{2}$	0	$3\frac{1}{2}$
in thickness, at the gunwale, . .			0	5	0	$4\frac{1}{2}$	0	4	0	4	0	4	0	4	0	$3\frac{1}{2}$
at the rail, . . .			0	4	0	$3\frac{1}{2}$	0	3	0	3	0	3	0	3	0	$2\frac{1}{2}$
The stanchions, where intended to serve as timber-heads, to be as large as necessary.																
Stanchions on the Fore-poop, and ditto After-poop,—																
To be in breadth, at the gunwale, . .	0	5	0	5												
at the rail, . . .	0	$4\frac{1}{2}$	0	$4\frac{1}{2}$												
in thickness, at the gunwale, .	0	$3\frac{1}{2}$	0	$3\frac{1}{2}$												
at the rail, . . .	0	$2\frac{1}{2}$	0	$2\frac{1}{2}$												
Covering Boards—The main covering board to be of English oak, in thickness . . .	0	$4\frac{1}{2}$	0	$4\frac{1}{2}$	0	$4\frac{1}{2}$	0	4	0	4	0	$3\frac{1}{2}$	0	$3\frac{1}{2}$	0	$2\frac{1}{2}$
To be bolted down to the water-ways and plank-sheer with iron bolts, in diameter . .	0	$0\frac{3}{4}$	0	$0\frac{3}{4}$	0	$0\frac{3}{4}$	0	$0\frac{5}{8}$	0	$0\frac{5}{8}$	0	$0\frac{5}{8}$	0	$0\frac{5}{8}$	0	$0\frac{1}{2}$
And to have a bolt passing through every stanchion and timber-head; the bolts to be clenched, and to be in diameter, ...	0	$0\frac{3}{4}$	0	$0\frac{3}{4}$	0	$0\frac{3}{4}$	0	$0\frac{5}{8}$	0	$0\frac{5}{8}$	0	$0\frac{5}{8}$	0	$0\frac{5}{8}$	0	$0\frac{1}{2}$
The covering boards on the poop deck of the two large ships, also of English oak, of a sufficient breadth, and in thickness	0	3	0	3												
To be fastened down in the same manner as the covering boards on the main gunwale; but the bolts which pass through the stanchions and timber-heads, to be in diameter . . .	0	$0\frac{3}{4}$	0	$0\frac{3}{4}$												
And those for fixing them down to the water-ways and plank-sheer to be in diameter .	0	$0\frac{5}{8}$	0	$0\frac{5}{8}$												
Main-Rail—To be of American elm, in breadth	1	4	1	0	0	10	0	9	0	$8\frac{1}{2}$	0	7	0	6	0	4
in thickness	0	$5\frac{1}{2}$	0	5	0	$4\frac{3}{4}$	0	$4\frac{1}{2}$	0	$4\frac{1}{2}$	0	$4\frac{1}{2}$	0	4	0	$3\frac{1}{2}$
and to have mouldings on both edges.																
Rail on the Poop forward and aft—Of American elm, in breadth . . .	0	$6\frac{1}{2}$	0	6	0	4										
in thickness . . .	0	3	0	3	0	$2\frac{1}{2}$										
Taffrail—to be of ...... oak,* in breadth, at middle,	1	2	1	2	1	2	0	12	0	12	0	13	0	11	0	$9\frac{1}{2}$
in breadth, at the side rail,	1	1	1	1	1	1	0	10	0	10	0	10	0	9	0	8
to be in thickness throughout	0	6	0	5	0	$4\frac{1}{2}$	0	4	0	$3\frac{1}{2}$	0	$3\frac{1}{2}$	0	$3\frac{1}{2}$	0	$2\frac{1}{2}$
As it will be difficult to procure plank of the breadth as specified above, a piece of a proportional size may be bolted on the after edge to make up the round of the rails according to the round aft of the stern. The height of all the rails to be the same as represented on the plan. All the taffrails to be kneed to the side rails.																
(To complete channel-wales and chain-work, with all other eye-bolts, plates, rings, and iron work of every description that is attached to the hull of the vessel, and which is connected with the carpentry work necessary for the completion of the vessel, whether herein mentioned or not.)																
Rudder—To be made after the most approved manner, copper-bolted, and fitted with copper or composition rudder-bands of the best quality—																
Number of bands below the counter . .	five		four		four		four		three		three		three		three	
Diameter of the pintle of the lower band .	0	$2\frac{7}{8}$	0	$2\frac{7}{8}$	0	$2\frac{3}{4}$	0	$2\frac{3}{4}$	0	$2\frac{5}{8}$	0	$2\frac{5}{8}$	0	$2\frac{1}{2}$	0	$1\frac{3}{4}$
Ditto of the second band .	0	$2\frac{3}{4}$	0	$2\frac{5}{8}$	0	$2\frac{11}{16}$	0	$2\frac{1}{2}$	0	$2\frac{1}{2}$	0	$2\frac{5}{16}$	0	$2\frac{6}{16}$	0	$1\frac{5}{8}$

* If any other light and weak timber be employed for what we have specified as oak, the dimensions of the pieces must be increased in proportion to the comparative strength of the kind of materials.

Specification of different parts, qualities of Materials, &c.	*Dimensions in Feet, Inches, and Eighth Parts, &c.*															
Denomination, Tonnage of each,	*Ship*, 503.		*Ship*, 400.		*Ship*, 347.		*Brig*, 303.		*Brig*, 206.		*Schooner*, 251.		*Smack*, 174.		*Sloop*, 62.	
Rudder (*continued.*)—	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.
Diameter of the pintle of the third band . .	0	2¾	0	2¾	0	2⅛	0	2⅜	0	2⅜	0	2⅛	0	2¼	0	1 7/16
Ditto of the fourth band . .	0	2¾	0	2⅝	0	2½	0	2⅜								
Ditto of the fifth band . . .	0	2½														
Cabin and Forecastle Deck*—To be American yellow pine, in thickness							0	2½	0	2	0	2	0	2	0	1¾
Cabin deck, in length from the seat of the transoms to the main bulkhead.																
Forecastle and steerage deck, in length from the stem to the hold bulkhead.																
Coamings for the cabin skylights, to be either elliptical, circular, or square, as required.																
Out-board Work.																
Main Channels—To be of oak, in length . . .	20	0	17	0	16	0	16	0	15	0	14	0	13	6	10	0
in thickness at the inner edge,	0	5½	0	5	0	4½	0	4	0	3½	0	3½	0	7½	0	5
ditto at the outer edge,	0	4½	0	3½	0	3	0	3	0	2½	0	2½	0	4	0	2½
in breadth	2	0	1	9	1	6	1	6	1	4	1	2	1	0	0	9
or broader, if required to clear the shrouds from the rails, &c.																
To be bolted to the side with bolts, in number	seven		seven		seven		seven		six		five		four		four	
in diameter	0	1	0	1	0	1	0	1	0	0⅞	0	0⅞	0	0⅞	0	0¾
Fore Channel—Oak, in length	20	0	17	0	16	0	16	0	15	0	14	0				
in thickness at the inner edge,	0	5½	0	5	0	4½	0	4	0	3½	0	3½				
ditto at the outer edge,	0	4½	0	3½	0	3	0	3	0	2½	0	2½				
in breadth, ...	2	0	1	9	1	6	1	6	1	4	1	2				
or broader, if required to clear the shrouds of the rails, &c.																
To be bolted the same as the main-channels.																
Mizen Channel—Oak, in length	13	6	11	0	10	0										
Of a proportional thickness, and to be of sufficient breadth to clear the shrouds with the top-gallant rail, &c. to be properly bolted.																
All the channels to be supported with iron knees or straps; number, fore channel . . .	four		four		four		four		three							
„ main channel . . .	four		four		four		four		three							
„ mizen channel . . .	three		three		three		three		two							
To be of a proper thickness, and to have a sufficient number of bolts in each.																
Head—Projection of the cutwater from the under side of the bowsprit, at the front of the main-stem, to the shoulders of the figure, as per the plan.																
Rails of the Head—to be of oak, as also the knees and timbers; to be moulded, and neatly finished with carved work.																
Lead, for the fore part of the cutwater, in lbs. to the square foot, ...	12 lbs.		12 lbs.		12 lbs.		10 lbs.		10 lbs.							
Quarter-galleries, in length	10	0	9	3												
in depth, ...	8	4	7	0												
Greatest projection thwart ship, ...	4	6	3	3												

* In the large ships, the main and 'twixt-decks are the cabin-deck, &c

MARINE ARCHITECTURE.

PART III.

PRACTICE OF SHIPBUILDING.

CHAPTER I.

ON LAYING OFF THE PLAN IN THE FLOOR OF THE MOULDING-LOFT, AND CARRYING ON THE BUILDING AND LAUNCHING OF THE VESSEL.

The First Operation is to Lay down the Ship from the Plan.

HAVING drawn and completed the whole of the moulding plans, sections, &c. according to the directions contained in the preceding chapters, the vessel is now to be laid down; that is to say, the whole plan of the vessel is to be drawn at full size on the floor of the moulding-loft, or a large platform of deals, prepared for that purpose. The floor of the moulding-loft should be equal in length to at least the half-length of the vessel, but if it is sufficient to take in the whole length, it will answer so much the better; it should be of a sufficient breadth to take in the full height of the ship, from the keel to the top of the stern. The floor should be as level and smooth as possible, and coated over with black size, that the lines, which are drawn with chalk, may be distinctly seen, and easily rubbed out or struck in where required.

The platform or moulding-loft being prepared, make a proper set of battens for describing the curve-lines on the floor; these should be made of the finest fir, and as long as can be got clear of knots or other defects, which might cause them to break when bending to the curves. The battens for drawing the ribband and water-lines are the longest, being generally about 40 feet in length, 1¼ inch thick, by 1½ inch in breadth at the middle, and tapered regularly towards the end; particularly the ends of such as are for bending round the bow or buttock should be thinned off to a half or 3-8ths of an inch, in order that they may bend fair, without the risk of breaking. The thick ends, which come towards the middle of the vessel, are commonly made so as to join fair to the ends of each other, by means of what is called a tongue and lip scarph or joint, to prevent the end of the one from coming past the other, when drawing the sheer, or any other fair curves. There are also a small kind of battens used for draw-

ing the form of the timbers, or other quick curves in the body-plan, which should be about 3-4ths of an inch in breadth and one half-inch thick, to near the ends, which must be thinned off to about 1-4th of an inch in thickness, &c. A good long square will be found very convenient; also four or five dozen of nails should be provided, for sticking into the floor by the sides of the battens, to bend and keep them to the proper curve, according to the off-sets and measurements from the plan. These nails will require to be about $4\frac{1}{2}$ inches long, and a little more than 1-4th of an inch thick; they should also be quite round, with broad round heads and sharp points, so as to be easily struck into or drawn from the floor by the hand, without the assistance of hammers or pincers; the sharp point is not only more convenient, but also less injurious to the floor. Likewise, for ease, exactness, and dispatch, in measuring the dimensions on the floor, provide two measuring battens, one of 8 or 10 feet in length, and the other equal to the length of the longest diagonal in the body-plan; mark them feet, inches, half-inches, and quarters of inches. They are generally made of dry wood, two inches in breadth, and about 5-8ths of an inch thick in the middle, and thinned off, so that the thin edges can be applied to the floor, and the feet, inches, &c. marked off with greater exactness than with the common rule.

Being now ready to lay down, first measure the size of the loft, and observe in what position it will be most convenient for the extension of your plan. Supposing the loft is of sufficient length to take in one half of the extreme length of the vessel, you may commence first with the fore-body, and proceed as follows:—Measure up from one side of the floor of the loft, the full height of the stem, and if there is room to spare in the breadth of the loft, suppose three feet, you may strike a straight line the whole length of the loft, 2 or 3 feet from the wall at one side. This line must be perfectly straight, as it is intended to represent the upper edge of the rabbet of the keel, the base-line of the body-plan, and the centre-line of the floor-plane. At the end of the moulding-loft, and as near the wall as may be convenient, raise a perpendicular from the base-line to represent the vertical line which is drawn from the foreside of the main-stem where it is cut by the under side of the bowsprit (*as on the Plan.*) On the base-line, measure aft from this perpendicular, say the exact distance between it, and the place of your third or fourth square frame; and at this place raise a perpendicular, by the training of a batten centering at equal distances from the point at which the perpendicular is to be raised; (raising this perpendicular is merely to ensure the correctness of the vertical lines). Having proved this line to be perfectly upright, set off from the front line of the stem, or foremost perpendicular, the place of all the other vertical lines, so far aft as the length of the loft will permit, making them perpendicular to the base-line, and to represent the centre-lines of all the frames, the character of which must be marked as on the plan. From the foremost perpendicular, set off all the rakes of the stem, inside and out; measure up the corresponding heights, also the entire height of the stem; measure the level distance from the front line of the stem (*on the Plan*) to where the main-breadth cuts the inside and outside of the hoods or rabbet; transfer this height and distance to the floor; also in the same manner measure the lower edge of the bends, the different water-lines, the height of the first ribband-line, the place of the foremost

square-frame, also the place of the trying and adjusting frames; strike all these lines up vertically, and on each measure up from the base-line the heights of the stem and rabbet-line at each respectively, and you will have points through which to draw the inside of the stem, the outside of the rabbet, also the front line of the stem; take a batten and bend it round, drawing first the inside of the stem from the top to reconcile with the upper edge of the keel, the outside of the rabbet, and lastly the front of the stem and gripe down to the bottom of the keel.

Having the stem and centre-lines of all the frames laid down, next set off the height of the bends, upper and lower height of breadth lines, and top-height line, on their respective frames; then bend a batten or battens along, so as to cut the points of each line; draw along the edge of the batten with a piece of sharp chalk, and so complete the sheer-lines.

The next thing to be done is to draw in the main-breadth line on the floor-plane, the off-sets for which must be measured from the plan with the compasses, and extended on the respective frames on the loft, making the base-line, or line which represents the upper edge of the keel, the centre-line. To find the place where the main-breadth line ends at the stem, set off the half-thickness of the stem from the centre-line, the same as before directed for drawing the plan on the paper. Let fall a perpendicular from where the upper height of main-breadth cuts the outside of the rabbet of the stem in the sheer-plan to the centre-line of the floor-plane. On this line set the half-thickness of the stem from the centre-line; then on that point as a centre, and with the thickness of the hooding-ends as a radius, sweep an arc of a circle inwards; then draw the fore end of your main-breadth line to come in at the back of this circle.

This much of the sheer-plan being laid down, proceed to erect the body-plan. Take one of the frame-lines for a centre-line, in order to make as few lines on the floor as possible, and thereby prevent confusion; set up the tangent-lines at the exact half-breadth of the midship-frame, on each side of the centre-line; also strike up lines for the half-thickness of the stem and stern-post; make a section of the keel exactly under the centre-line, and draw in the form of the rabbet at midships. Strike in all the diagonals, and be very particular in measuring them from the plan. Mark the half-length of the midship-floor on each side of the centre-line; draw up with your square a line from this point, and on it mark from the base-line the neat rise of the midship-frame (if your diagonals are right drawn, this spot will be exactly in the line of the second one); try how it agrees with your measurement from the plan on the second diagonal, by way of proof to see if the diagonals are properly placed; if they are not exact, you must have recourse to some alteration to make them so, otherwise the whole of the laying off will be more or less affected thereby. When they are found to be correct, strike a line quite straight from the rise of the floor on the second diagonal to the upper edge of the rabbet of the keel—this will then be the midship-floor; but it must be understood, that although this length is considered the proportioning length of the floor or the length of its straight part from the centre each way, the real floor-timbers are always made from 6 to 10 or 12 inches longer than the length cut off by the second diagonal, according as they can be got, and the shiftings of the other timbers allow. It

is therefore necessary to distinguish this length from that of the extreme length of the floor. The spot where the second diagonal cuts the floors is called the floor-sirmark. From the lines already laid down on the sheer-plan, take off the height of the lower height of breadth, the upper height of breadth, and the top-height, at the frame; mark these heights on the centre and side-lines of your body-plan; then with a chalk line, strike lines across the body-plan at these heights; measure the main and top-breadths from the lines on the floor-plane, and set the same on their respective lines of height on the body-plan. The mean-breadth mark will, if you have been exact in setting the measurements off, come exactly into the side or tangent-lines of the midship-frame; the top-breadth will of course come as much within these lines as the midship-frame rounds in, or, in the technical term, as much as the tumble-home of the side at the midship-frame. Next draw your midship-frame, by bending round the thin batten to the proper marks on the different diagonals. A little attention is required in bending the batten: bring the lower end of it along the straight part of the floor, say 2 feet, in order to make the round of the bilge reconcile well with the floor; fix the under end firmly with the nails, placing one on the outside and inside alternately, if required; stick a nail at the side of all the diagonals, the thickness of the batten within the offset; then bend the batten round, making it to coincide with the side-line at the lower height of breadth; fix it firmly in this position by sticking in the nails on each side, observing to place one in the inside of the batten at the upper height of main-breadth. Bend in the top of the batten to the proper mark on the top height of breadth line; then draw round the outside of the batten with chalk, and proceed to the other side of the frame, and draw it in the same manner, and so the midship-frame will be completed. After which, proceed with all the others in the same manner, measuring them off from the plan, and setting their distances from the centre-line down all the diagonals in the floor of the loft; also take the heights of the main and top breadths, and their respective breadths at each frame. These being already run in the loft, and supposed correct, are transferred from the sheer and floor-plane to the body-plan, and all the square-frames drawn in one after the other, in the very same manner as was done in drawing the plan of the vessel on the paper.

In order to prove whether the frames laid down are correct or not, the ribband-lines must be measured off from them, and run in the floor-plane; to do which, place a batten along the diagonals, making its end exactly touch the centre-line of the body-plan; mark with a sharp piece of chalk the edge of the batten, exactly at the point where the lines of the frames cut the diagonal; then set all these distances off from the centre-line of the floor-plane on all their respective frames, and these will be the spots through which to run the ribband-lines. To find their proper termination at the hoods, take the neat height from the base-line to where the diagonal cuts the side-line of the stem in the body-plan; set this height perpendicularly up from the base-line of the sheer-plan till it intersect the outside of the rabbet of the hoods on the stem; strike down this perpendicular to the floor-plane. On the body-plan, measure the diagonal half-thickness of the stem, that is, the distance from the centre-line down the diagonal to where it is cut by the line representing the side of the stem; set this distance from

the centre-line of the floor-plane on the perpendicular which you have let fall from the hoods, and this will give the extended half-thickness of the stem. On this point as a centre, and with the diagonal thickness of the plank in the compasses as a radius, describe an arc of a circle inwards; then proceed to bend the batten round to the spots on the frames, bringing its end in so as to touch the back of this circle, which will give the opening of the rabbet of the hoods, and termination of the ribband-line. Now, should this line not appear quite fair, you must have recourse to some alteration on the frames already drawn in the body-plan, by observing which or what part of the frames are slack or full, and how far they may be altered, so as to make fair curves, both in a vertical and horizontal direction. This must always be particularly attended to. Then correct them accordingly.

The frames in the body-plan are laid down first, because of their being easier adjusted than the ribband-lines. The water-lines may next be taken off, and run in the floor-plane, and the whole of the work laid down and corrected in the same manner as before directed for completing the plan on paper; that is to say, the cant-frames are to be laid down, also the hawse-timbers and cut-water; and after the whole timbers are laid down and corrected, you should then proceed to make the moulds, the harpins, &c., and mark off all their bevellings on a board provided for that purpose.

The wood for making the moulds should be well seasoned, to prevent them from casting or twisting, and thereby destroying the proper mould of the timbers. To make the moulds, procure several clefts of dry American deal, of 5-8ths or 3-4ths of an inch thick; let the deals be perfectly free from shakes; plane them up on both sides. As we have laid down the fore-body, first proceed to make the moulds for it, commencing first with the floor-moulds. Some builders make a mould for all the floors in the fore and after bodies, by making the inside, as well as the outside, a mould; others consider this unnecessary.

To make the floor-moulds, you must first measure the rise of all the floors; mark them on the opposite side of the diagonal, as shewn by *Fig.* 5, *Plate* XII.; then strike them in where they run straight from the sir-mark to the side of the keel; and those which partake of a hollow, you must draw with the batten. Having the floors drawn on both sides of the centre-line, take a piece of deal; fit its edge very correctly to the line representing the floor of your midship-frame; when this is done, rip it off the board, making the mould about 6 or 7 inches broad; cut the ends off about 8 or 10 inches longer than the length of the floor at the sir-marks; sprig the mould down to the floor of the loft, making its edge coincide with the line of the midship-frame; then bind it across with a tie-piece, flinching the ends off, so that it may be flush with the face of the mould; mark the centre and side-lines of the keel on the mould; also the floor-sirmarks, and the diagonals forming the floor-guide. The use of having these marked on the mould will subsequently be shewn. Lastly, for that mould mark the distinguishing character of the frame on it, and it is then completed, (this is called a single mould.) Next proceed to fit the first futtock-mould, the second, third, and (in large vessels) the fourth futtock, and also the long and short top-timber moulds. Be particular in marking all the diagonals on the moulds, also their names, and the

frame for which they have been fitted. Observe, that in making the moulds, they must always be long enough to cross the diagonals a little, so as to overlap each other, say about 10 or 12 inches.

Some shipbuilders make a kind of mould on which is marked the rise of all the floors, in place of making a floor-mould for every frame, the one side serving for the fore-body floors, and the other for the after-body floors, as represented by *Fig.* 5, *Plate* XII. It is composed of eight pieces of thin board, forming two right-angled triangles, joined together by their perpendicular sides; but in order that the mould may be as convenient as possible, the two pieces are joined together with two small hinges, as seen in the figure. In marking the rise of the floors on this mould, the base or horizontal pieces are laid to coincide with the base-line of the body-plan, with the hinged joint coinciding with the centre-line, and the intersection of the line of the different frames with the floor-guide and floor-sirmark are marked on the diagonal pieces of the mould, as these pieces are laid to coincide with the diagonals respectively, and the corresponding distinguishing character of each frame, that is, the names of the frames to which the floors belong; also the cutting down of every floor must be squared across the centre part of the mould. Now, to mould any of the floors with this mould, you have only to place it on the piece of timber, mark its rise at the sirmark and floor-guide, also its seat, the centre and side lines of the keel; then lift off the floor-mould, take the first futtock-mould, and draw both sides of the floor, and it will then be moulded as correct as if it had been done by a single floor-mould.

After the moulds for the square-frames are all made, make the moulds for the cant-frames, also for the main, top, and bend harpins; and if the vessel is large, make a mould to the second and third diagonal ribbands, sufficient in length to reach from the rabbet of the hoods to the foremost square-frame.

The moulds being made for the fore-body of the vessel, before rubbing out your lines, and proceeding with the after-body, first take the bevellings of all the fore-body frames, cant-timbers, harpins, &c.

When the body-plan of a vessel is laid down, it only represents the extremity and form of the transverse sections at the centre of the frames, and in this case these may be considered of no thickness. But the timbers of the real frames which compose the vessel must be of a determinate thickness, according to the size of the vessel, or the agreement of the parties who contract for the building. The sides of these timbers form so many planes crossing the vessel at right angles, both in a horizontal and vertical direction, so far as the square-frames are continued. Then, as there is but a very small portion of the sides or bottom of any ship that runs parallel to the keel or centre-line, but is narrowing or rounding-in towards the bow and stern, the outer edges of these timbers, the sides of which form the transverse planes mentioned, must be hewn or sawn so as to agree with the longitudinal curving of the sides and bottom of the ship; and it is the angles which the outside surface of these timbers form with the plane of their sides that are called the bevellings of the timbers. When the bevel is applied on the moulding side of any timber, and the angle of the timber falls within a right angle, it is said to be an under-bevel; but if the angle to which the timber is

dressed, or to be dressed, is without a right angle, it is called a standing-bevel. Supposing the sides of all the framing timbers to be dressed straight and out of winding, and then moulded to the proper curve, it must be sawn or hewn to the proper bevelling, so that the outside may run fair with the rounding of the vessel. Now it is these bevellings, or the angles which each timber should form with its moulding side, which we require to find from the plan of the vessel, either on the extended lines in the moulding-loft, or from the plan on the paper, as they can be taken from either, but a little more correctly from the lines on the loft.

When the diagonals on the body-plan are placed as before recommended, the plane of the ribband-lines will run in a direction nearly at right angles to the curve of their moulding edges, at least so near as to make no material difference of the bevellings of the frames. Hence, in taking the bevellings of the square-frames, that is, the bevellings of all the timbers of which these frames are made, you have only to apply the stock of the bevel, or lay it parallel to the straight lines representing the plane of the frames on the floor-plane; then bring the tongue of the bevel along the ribband-line, making it to coincide with the angle which the ribband-line forms with the line of the frame, at a breadth equal to the siding of the timber at that ribband-line. In this manner take the bevelling at all the other ribband-lines on the same, and all the other frames, marking them on a board with their proper names, as *B. 1st R.*, for bevelling at the first diagonal or floor-guide of frame B; *2d R.* for the bevel of the second diagonal ribband, or floor-sirmark; *3d R.* for the third; *M. B.* for the bevel at the main-breadth sirmark; *T.B.* for that of the top-breadth, and so on. In this manner you may take as many bevellings as you have ribband-lines run in the floor-plane. In taking the bevellings from the ribband-lines, it may be observed, that on the round of the bow the timber on the foreside of the frame will require a little more bevel than the one on the afterside, which some are at the trouble of taking. At the same time, this is almost unnecessary, except for the timbers which are situated at some suddenly rounding part. I have commonly found it sufficiently near to take the bevel right across the centre, which will answer for both timbers; and by trimming any unfair parts of it from the bevelling edges of the timbers after the frames are put together, and only taking it half way across each timber, or so, this will bring a small round on the back of the frame. The bevel-stock at the same time must be placed at the sir-mark, with its stock lying across the timber, in the direction of the diagonal.

I shall now describe the method which I commonly use in taking the bevellings off the plan, as in some cases it is very convenient, particularly when there is not a proper moulding-loft, or one so small as only to contain the body-plan, or where there is only a platform laid in the yard for that purpose. In this case much, indeed the whole, depends upon the accuracy of the plan, and care in taking them off, as to whether the frames will go fair when set up, as you will be deprived of correcting them in the floor-plane. But when you are so situated, it is the best way to draw the plan of the vessel on as large a scale as convenient, say on 1-3d or one-half inch to the foot, when it is a small vessel; which, if drawn correctly, the frames may be laid down, and the bevellings taken to a tolerable degree of exactness.

For taking the bevellings from the plan on the paper, you should be provided with a a small brass bevel. Supposing the stock to be 6 inches long, and the tongue 5½ inches, about half an inch in breadth, and 3-16ths of an inch in thickness; having this small bevel, the most correct method of taking the bevels with it is to lay a flat straight-edged ruler across the floor-plane, parallel to the lines which represent the frames, laying some weights on it so as to prevent it from shifting, and keeping it about one inch back from the frame of which the bevellings are to be taken. Then begin with the lowest diagonal ribband-line; keep the back of the bevel-stock against the edge of the ruler; set the tongue of the bevel across the frame-line and in the proper direction of the ribband-line, at a small distance either above or below it, so that you can see when it is set properly to the line at that part where it crosses the line of the frame. I generally commence first with the first diagonal ribband, then the second and third, and so on, with lower harpin, main and top breadth, &c. Having two or three fir boards of about 2 feet long and 4 or 5 inches broad, with the edges quite straight and parallel to each other, draw the different bevels on these boards, marking the proper names on each; and with these you may take as many bevellings as you have, or may please to draw ribband-lines for in the floor-plane; also take as many bevellings as will be required for all your square-frames.

Another method of taking the bevellings of the square-frames, and which is equally convenient, when the plan is fixed on a board, and you have a square with a shifting stock, is to set the shifting side of the stock against the end of the drawing board, then to bring the edge of the square blade to cross the line of the frame at the ribband-line, making it to coincide with the angle which the diagonal ribband-line makes with the centre-line of the frame; then to apply the stock of the square to the edge of the bevel-board, and draw the bevel.

The bevellings of the square-frames may be taken by the following method, which is often used in building large ships, particularly when the framing timber is converted at a distance from the building-yard. Suppose a frame at every other floor is first laid down in the body-plan, and the fore-and-aft lines run in the floor-plane, and all to be nearly correct; then strike in the intermediate frames in the floor-plane, and transfer them to the body-plan,—you will then have a frame at every floor (this is done although only every other floor is to be made a frame); then, in making the moulds for every other frame, also make the inside of every mould to fit the curve of the intermediate frame, and in this way you will have a mould for every timber from the foremost to the aftermost square-frame. And if the cant-frames are moulded, and the moulds made in the same manner, there will then be a mould for every timber in the ship from the hawse to the stern-frame, every mould answering for two timbers, the one on its foreside, and the other on its afterside. Now, to find the bevel of the timbers, without taking them off from the ribband-lines: With the compasses, set a point between each of the frames in the body-plan, at the diagonal or sir-mark a little nearer the frame immediately abaft them, allowing the side divisions between the points and the next frame before them to be a little wider than the divisions between the points and the next frame abaft them, as you will observe the frames open or widen gradually as they ap-

proach the bow or stern of the vessel; thus the midship-frames in the body-plan are very close to one another, and those towards the bow and stern wider, according to the great rounding of those parts of the vessel. Place the points between each frame in the same proportion as they appear to widen with one another; take a thin slip of wood, about an inch in breadth, and as long as to reach between the two widest frames; thin or beard off the edges of the slip quite sharp; and then, suppose you begin at the midship-frame, set one end of the slip to the midship-frame, and with a pencil mark on its edge the point betwixt it and the next frame, and this will give how much the frame is to be cut under, or is within a square, when taken from the moulding side; so that by measuring from all the frames inwards, you will have how much all the frames bevel within a square from their moulding edge on that diagonal. If the spots are measured from the outside of the frames, it will give how much they bevel without a square from their moulding edges, *i. e.* the standing bevel; likewise, if the measure of the spots is taken right across in the nearest direction, you will only require to apply the stock of the bevel square across the timber (when making the frames), in place of keeping it lying in the direction of the diagonal. After having marked the measure of all the under or standing bevels on the short slip of wood at that diagonal, take a board as broad as the berthing of the timbers, which in a vessel of 200 tons is generally about 12 inches, that is, the distance from moulding edge to moulding edge of all the timbers. The board being thus made with its edges straight and parallel to each other, from a point near the one end of it, square across a line; then on the other edge, set off from the square line all the distances, as measured off from between the spots and the frames (on the body-plan), as marked on the short slip; then from each and all of the off-sets on the edge of the board, draw lines across to the point at the square line, and these lines will be all the bevellings of their respective frames on that ribband-line, represented by the diagonals they are taken from. And in this way the names of the ribband-lines are commonly marked upon the square line at the beginning of the bevellings for each diagonal, and the numbers of the frames are marked upon their respective bevels. The diagonal next to the keel is called the floor-guide, and the second one the floor-sirmark; but in some places the diagonals are distinguished by numbering them regularly from the keel upwards, as first, second, third, fourth diagonals, &c It answers fully as well, in place of having a bevelling board as broad as the berth and space of the timbers, which would be found a little inconvenient to carry about the yard, to mark the bevellings on a narrow board of about 6 or 7 inches in breadth. This is done in the same manner as before, by making a kind of small frame of narrow pieces of board thus: Take two straight battens or pieces of fir of 3 or 4 inches broad; place them parallel to each other at a little less distance between them than the berth and space of the timbers; nail two or three cross pieces upon the same side, making this side the back; then lay in between the two side battens your bevelling board of about 6 or 7 inches in breadth—A D and B C (*Plate* XII. *Fig.* 6) are the two side battens; L L the cross pieces; the dotted lines drawn down the side battens are distant from each other equal to the berth and space of the timbers; E F is the bevel board. The line on which *1st D'.* is marked is drawn square across; it has also this ⊕ on it,

because the dead-flat frame is square. Now this frame may be laid on a bench or table; and taking your short slip as before, on either of the parallel lines, either on the one A D or B C, suppose B C, set down from the square line all the measures which were taken from the points between the frames, as A, B, C, D, &c. and for expedition stick in a small nail at the other side of the square line, just where it is cut by the parallel line, as seen in the figure. All things being thus prepared, and the bevelling board E F lying between and parallel with the line A D and B C, take a straight-edge batten M M; lay one edge of it against the pin in the ruler A D; bring the other end of it to the marks A, B, C, &c. on the parallel line in batten B C, and draw lines across the bevel board, and these will be the bevels of all the frames (either of the fore or after-body, according as taken off) on that ribband; then with a piece of chalk, rub over all the marks A, B, C, &c. on the parallel line B C; slide up the bevel board, and proceed with the bevels of the next ribband in the same manner; and so on with all the lines at which you mean to take bevellings, from the keel to the gunwale.

The bevellings of all the cant-frames are taken in a similar manner, except that both sides of the timbers must be laid down in the body-plan, and the difference taken between the moulding edge and the other side or bevelling edge. If the line laid down for the bevelling edge of the timber comes within the line of the moulding edge, the timber will have an under-bevel at that place; and when without it, the timber will have a standing-bevel.

You must next proceed to lay down the after-body, make the moulds, and take the bevels of the timbers; but as this operation differs in nothing from that of laying down the fore-body, with the exception of some particulars, such as the moulding of the quarter-timbers, the transoms, &c. and we have taken particular notice of these in the directions for finding the moulds of the timbers, and completing the plan on the paper, it is unnecessary we should recapitulate farther than we have now done. I shall therefore proceed at once to offer a few practical directions for carrying on the work.

To prepare the Building Slip.—All things being ready for commencing with the work, the ground on which the vessel is to be built, if it has not been used as a building place, must be prepared in the following manner:—Level it the thwartship way, equal to the breadth of the intended vessel, and give it a declivity of one-half or 3-4ths of an inch to the foot in the direction in which you intend to launch. Likewise observe the state of the ground: If partially soft, it will be necessary to make 6 or 8 feet of its breadth along the middle, where the blocks for the keel are to stand, somewhat lower than the other parts, and make the low part quite level the thwartship way; cover it over with any old plank, laying them the fore-and-aft way, and bedding them solidly to the ground, in order to prevent any sudden settling where the blocks may be placed.

To prepare and lay the Blocks.—Procure a number of pieces of hard timber or blocks of wood, of from 2 to 5 feet in length, and any convenient depth and breadth, as 2 feet, 18 or 16 inches; make their sides straight and square. Measure the length of the keel along the ground, and place the foremost and aftermost blocks first; fit the longer pieces solidly to the ground-way, so that their upper edges may be level; fasten

them down to the ground-way with a nail in each corner; lay other shorter pieces on the top of these, and fasten them to the lower or ground-tier with a treenail in each end; and so on, until you make up the height of about three feet. Observe, in placing the blocks, that the keel should only have a declivity of one half-inch on a foot, if the nature of the ground and other circumstances will allow, making the blocks stand perpendicular. Make the upper pieces, or caps of the blocks, of about 8 or 10 inches in thickness, of good clean timber clear of knots, so that they may be easily split out if required, for fixing the false keel on, or at the time of launching; also fix these pieces to the upper block, with a nail in each end, making their upper sides completely level and out of winding with each other; chack out a notch of one inch thick in their upper side, sufficient to take in the breadth of the keel, in order to prevent it from shifting to one side. The intermediate blocks are laid in the same manner, and are generally placed about 4 or 5 feet apart, according to the magnitude of the vessel, except that when it is intended to lay the keel on very high blocks, some of them are placed in an angled direction to the keel, in place of being square across, as is usual; for by angling some of the blocks in this manner, the vessel is much prevented from vibrating or shaking when hoisting in the heavy parts, as the kelsons, beams, or such like. The blocks should be laid so that the keel may form a curve downwards of about one inch on every 50 feet of its length, to make an allowance for its hogging, so that it will come nearly straight when the vessel is launched.

To Work the Keel, Stem and Stern-Post, &c.—In preparing the different parts of the framing, the keel, stem, and stern-post are commonly the first begun with; these pieces are sided to the size as agreed upon by the contract (*see the Table of dimensions*); the lengths are likewise as near thereto as can be got.

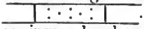
The different pieces of which the keel is to be made being pointed out to suit the dimensions of the vessel as near as possible, allowing for the lengths of the scarphs, &c., they are to be dressed square to the proper size, and then scarphed together.

To scarph the keel-pieces properly together is a very particular part of the work, the keel being exposed to very considerable strains, and being also very difficult to be got at should any repairs be required; the scarphs of the keel should therefore be done in a very substantial manner. After having the lengths sought out, the scarphs must be placed to the best advantage, both for strength and the accommodation of all the adjacent parts of the work. If the keel is in two lengths, the scarphs will probably come near the middle of the ship; in which case you must observe to have the kelson placed so that it shall strengthen that part of the ship as much as possible; likewise the butts of the bottom plank must be shifted well clear of the scarph of the keel. When the keel is in three pieces, the scarph of the after piece should come under the dead-wood, as it is preferable having it there than at any other place.

The Scarphs of the Keel should never be shorter than 4½ times the berth and space of the floors, and not longer than 6½ times the same. Thus, when the berth and space of the floor-timbers is 12 inches, the length of the scarphs will be 4 feet 6 inches; and at this length both points of the scarphs will come exactly under floors, as will also 6 feet 6 inches bring the points under floors. This should always be attended to

if possible, but where the scarph happens to fall under some solid part of the dead-wood, it is not necessary to be so particular.

The lengths of the keel-scarphs being determined, they must be lined out, keeping the small end 1-3d of the thickness of the keel, and the other 2-3ds. When this is cut out, and the two pieces joined together, the keel will then be uniformly thick throughout, being the same at the scarph as at any other place. This method of joining the keel is represented by *Fig.* 4, *Plate* X., and is called plain scarphing. The seam of the scarph is sometimes laid horizontally, but oftener in an up-and-down way, as it is much stronger in the latter position. But there are various opinions respecting the scarphing of keels. In many parts of the west of England, the flat scarph is preferred; that is, the end of the one piece is laid above the other, making the seam lie horizontally. This method is approved of, because it is easier come at should it require caulking, and answers very well when covered with a false keel; but it is inferior to a vertical or side scarph when properly put together. Therefore, in order to make a proper vertical scarph, when you line it out as if to make the neat size of the keel or plain scarphs, strike another line on each of the pieces 3-4ths of an inch farther out, making each piece that much larger than for a plain scarph. Then, supposing the scarphs to be sawn out, and all their ends to be squared over from the middle line of the keel, draw a square line across the middle of the length of the scarphs; square both ends across the other way; then take your saw, and cut down between the middle draught of the scarph, and also the thick end of both the pieces, as far as the first drawn line, leaving the additional 3-4ths of an inch on both points or small ends of the pieces. (*See Figs.* 5 *and* 5′, *Plate* X.) Next line out a cog or tabling piece along the middle of the scarph, making it about 1-3d or 1-4th of the deepness of the keel in breadth; then cut out a mortise from the middle of the length of the scarph up to the butt at the thick end, 1-3d of the depth of the keel in breadth, and 3-4ths of an inch in deepness; next dress off the wood from each side of the projecting cog on the thin end of the scarph, leaving the tenon to project up 3-4ths of an inch, so that it will fit exactly into the mortise or hollow which is cut out of their opposite pieces; and observe to keep the cogs or tenons a little long from the points to the middle, for the purpose of drawing the butt-ends of the scarphs close up.

But before the keel is put together, and the scarphs bolted, it is better to cut out the rabbet for the edge of the garboard-strake on each side, as it will be more convenient for getting the pieces canted singly than after they are fastened together. In cutting out the rabbet of the keel, leave three or four feet from both ends to be cut out afterwards when the pieces are joined together. The rabbet is cut out in form of a V, having its breadth equal to the thickness of the garboard-plank, and depth 2-3ds of its breadth. After the rabbet is cut out, lay the pieces of the keel quite straight and fair upon the blocks. Tar both sides of the scarph; put a piece of flannel betwixt them; screw or wedge them close together, and fasten them with eight bolts, placed thus:—

. These bolts must have large heads, and be riveted or clenched on rings; also observe to keep them clear of the rabbet, and three or four inches from the lower side of the keel. This being done, cut a groove along the seam of the scarph

on the upper side, one inch deep and one and a half inches wide; caulk the seam of the scarph with a stripe of flannel, and a thread of oakum on the top of it; then fit a piece of dry oak into the groove; tar the groove well, and drive the piece tight down with a piece of tarred flannel under and round it, and fasten it down with a few copper nails or oak pins drove in with a small angle. By this means, the scarph will be perfectly water-tight, independent of the lower side, which however may be lightly caulked. Scarphs done in this manner I have never known to require caulking afterwards. The pieces of the keel being thus scarphed together, and bolted, it is now laid fair on the blocks, perfectly straight the side way, and a small treenail drove into several of the blocks at each side of the keel, to prevent it from being shifted or put off the straight the side way.

False Keel.—Sometimes the false keel is fitted to the under side of the main keel, and both laid on the blocks at the same time; but it is preferable to put to the false keel afterwards, when all the floor and kelson-bolts are clinched and made tight on the under side of the main keel, that, in the event of its being chafed off, the vessel may be tight; for when the floor and kelson-bolts are put through, and clenched on the false keel, if it should be chafed or rubbed off, the bolts will be twisted, and less or more widen the bolt-holes, and consequently they become leaky.

The keel being laid on the blocks, its proper length must be exactly measured off with a batten, and the scarph or seat of the stem and stern-posts marked out; also the station of all the frames and moulding-edges of the floors measured off, and raced in across the top and down the sides of the keel; also the exact place of all the cant-frames, and the heel of the stern-post.

Dead-wood.—The principal pieces of dead-wood (marked K, *Plate* X. *Fig.* 11) may now be fitted on the after end of the keel with dowals or cogs, as shewn on the plate. They may be fitted on after the stem and stern-frame is set up.

Stem.—The stem must be sided and moulded according to the dimension agreed on by contract, or to the size given in the Table of Dimensions. (*See also Rules and Proportions*, p. 157.)

The Stem and Apron-pieces are very principal timbers of the vessel, and should always be of the best quality, as they are difficult to get repaired; and should either of them rot or decay before the other parts of the ship, the hooding-ends of the plank get quite loose and wide.

When the timber designed for the stem is sided straight, and out of winding, begin and mould any of the pieces either at the top or bottom; draw the inside and outside of the rabbet fair by the stem-mould, according to the designed station of the piece, at the same time marking upon the mould how far the piece will work; also the length and position of the intended scarph. But before cutting the pieces so moulded, you will require to know how far the next piece will answer the mould, because a small alteration in the way of moulding or placing the scarphs may be of considerable importance in working the next piece to the greatest advantage. The length of the scarphs of the two pieces of the stem is three times its breadth; also the inner point of the scarph should be as thick as to come 1½ inches without the rabbet, in order that a

stop-water may at any time be put in. This scarph should be fitted and tabled in the same manner as the scarphs of the keel, only that the joints will lie across in the opposite direction. It should be fastened with six bolts, two in each point of the scarph, and two through the apron and breast-hook. Before moulding the lower piece of the stem, the depth of the fore-end of the keel should be considered, as a few inches additional depth at its fore-end will substitute for both the length and round of the lower piece of the stem. When the scarph of the stem is bolted, lay on the stem-mould, and draw on all the proper heights and marks on both sides, such as the top-height, main-height, height of the upper and lower edge of the bends, &c.

The Apron or Inner-stem should be of the most durable quality of timber, entirely free from shakes, sap-wood, and every other defect; it is sided a little larger than the stem at the lower end, and its size the fore-and-aft way equal to the moulding of the timbers, adding the thickness of the bottom planks. It is moulded to the inside curve of the stem, by the stem-mould. In very sharp vessels, the lower piece of the apron is very deep, as the long sloping feet of the bow-timbers are bevelled and fitted against it. It is sometimes of two or three pieces, joined together with short flat scarphs, as marked C C (*Fig.* 1′, *Plate* X.) The lowest piece, which fits along the keel and up the stem, is commonly called the stomach-piece or fore dead-wood. The scarphs of these pieces should be shifted well clear of the scarphs of the stem, and the stomach-piece should make a good shifting over the joining of the fore-end of the keel and stem. All the pieces of the apron must be neatly fayed to the inside of the stem, and the bolts so disposed, that when the breast-hook bolts are driven through, there will be a bolt every 18 or 20 inches from top to bottom. After the apron is bolted on the stem, the knight-heads or bollard-timbers are next to be wrought and bolted on the stem and apron-pieces, one on each side, and kept so far apart as to allow the bowsprit to lie between them on the stem-head. They are commonly as long as to reach down below the lower edge of the bends at the stem. When there is to be a raft-port in the upper part of the bends and black strakes, they should be as long as to make a shifting of the timbers below the port. For vessels of 250 tons and under, the knight-heads are commonly fastened and hoisted up with the stem, but in large vessels they are only fitted, and the holes bored for the bolts, and left till the stem is up and the harpins round, in order to make the stem as light as possible to hoist up; they are afterwards hoisted up, and bolted to the apron-pieces.

Fixing of the Stem to the fore-end of the Keel.—If the fore-end of the keel can be procured 1-4th or 1-3d deeper than at midships, it will answer much better than when it is of equal depth throughout, as this additional depth will accommodate the rounding of the lower end of the stem, and allow sufficient wood and room for making a more complete fastening, by means of boxing or scarphing in the stem to the keel, in a similar manner as the scarphs of the keel-pieces are fixed. Supposing the foot of the stem to come two or three feet along the top of the keel, cut down the keel, at the end of the stem, square across and down, about three inches, taking it off at nothing at the fore-end. This being done, and dressed perfectly level across, strike a line fore-and-aft the keel on one side at half the depth of the keel amidships from the bottom or lower side; also strike

another line along the upper side of the keel, where it has been dressed out, parallel to the centre-line of the keel, and one inch to the same side at which you struck the line on the side of the keel, *i. e.* the side which is to be chacked out, which leaves the keel side of the scarph the strongest. You must now cut off the bottom of the stem, so that it will come down to the line on the side of the keel, observing to give it such a bevel as will bring it to the proper fore-rake when set up; form a chack on the foot of the stem, and work a cog on the same, as represented by *Fig.* 6, *Plate* X., the piece A being the fore-end of the keel, and B the lower end of the stem; make a mould for the foot of the stem with its cog or coak, scribing it so that it will fit very completely; then apply this mould to the side of the keel; draw it very neatly, and then cut out the notch to the proper depth, but observing to leave sufficient wood to form a cog on the fore parts; dress out the chack or mortise very neatly, making them quite square, straight, and out of winding in every way. The scarph being thus far ready, observe where you can get a good bolt to pass through the foot of the stem and fore-end of the keel and apron or stomach-piece. Before setting the stem up, bore a hole through the deep side of the keel, by the side of the scarph, and nearly one inch clear of the seam, and you are then all ready to hoist up the stem.

Hoisting up the Stem.—In order to hoist up the stem, a pair of sheers must be erected a little before the end of the keel, and well guyed with ropes fore-and-aft. The stem is then brought under the sheers, and slung as near its centre of gravity as possible, or a very little above it, so that the foot of the stem may rather preponderate. When it is slung, and every thing properly secure, clap hands on the tackle, and hoist it steadily up, and steady it with ropes until it is properly shored, plumb to the right rake, and perfectly out of winding with the keel; but before setting in the scarph, tar it well, and put in the tarred flannel, which being done, screw all close up with a pair or two of cramps and a chain, and then bolt the scarph in the same manner as you did the other scarphs of the keel. There are commonly three proper shores used for steadying the stem, one on the front and one on each side; these rest on the stem, about the height of the bends. After the scarph is fastened, you must again try if the stem is standing quite plumb the side way, and to the proper rake, before setting it up for a full due. After the apron is fitted, bore up the hole which was put down through the keel at the side of the scarph, and drive a stout bolt down through all. By inspecting *Figs.* 6, 7, and 8 of the plate last referred to, it will be observed that there are other methods of scarphing the stem to the keel; that represented by *Fig.* 7 is most commonly employed, as it is rather the easiest executed, and at the same time makes a good fastening, but it is inferior to the other two. I consider the method which has been described as the best. It should be used in every case where a good fastening is wanted, but particularly for such vessels as have large gripes, (smacks, cutters, &c.) as it allows the end of the keel to run farther forward, which assists in reducing the size of the pieces for the gripe or lower end of the stem.

Stern-Post.—The stern-post should be of the best timber, quite free from shakes; particularly the fore-part should be entirely free from sap-wood. It should be sided about 11-12ths of the keel in midships, or 7-8ths of an inch for every two feet of the ship's ex-

treme breadth, and moulded at the keel one inch for every foot of the ship's extreme breadth, (if it can be got), and at the wing-transom 5-8ths of the breadth at the keel; or, as has before been noticed, make the moulding dimension double the siding at the keel, and line it to nearly square at the top. But should the timber not be large enough to make the stern-post to these proportions, the deficiency may be made up by a filling on the after-side of the lower end of the stern-post, or by a false stern-post.

After the stern-post is dressed straight and quite out of winding the siding way, it is then to be lined to its proper breadth the moulding way, and dressed square. On the floor of the moulding-loft, make a mould for the stern-post, and mark the seat of all the transoms, and height of the different ribbands on it; and when the post is dressed, lay on this mould, transfer the marks at the different heights, and scrive them on the post; also draw the outside of the rabbet, and the bevel of the heel of the post, allowing 3-8ths of its thickness for the length of the tenons; their breadth the thwartship way is 1-3d of the thickness of the post, and their length the fore-and-aft way is about twice their breadth.

If the main piece is large enough, it must have two tenons into the keel; also there should be a tenon on the inner-post 1-3d of its thickness, which will only be about half the thickness of the main-post. Care must also be taken to place the tenons on the main post so that a stop-water can be driven between it and the fore tenon and the rabbet of the hoods at the keel. The post being dressed to its proper dimensions, the tenons cut, and their corresponding mortises in the after-end of the keel, cant it with its after-edge up, and strike a middle-line on it; at the heel, set off equally from each side of the middle-line 2-3ds of the thickness; then from off at nothing at the seat of the wing-transom, strike a line on each side for the tapering of the after-side of the post; dress this off from both sides to within three inches of the rabbet of the hoods, and down from the wing-transom to within twice the thickness of the post, from the heel, which is near the place of the lower brace. After the brace is put on, and the rudder ready for hanging, the heel of the post is dressed fair downwards, and kept flush with the side of the brace. The post being tapered off towards the after-edge, it must now be turned with its fore-edge upwards, resting it on one or more blocks at the top end, to make sufficient room for working and dressing the transoms and fashion-timbers which compose the stern-frame.

Supposing the seat of the transoms and the ending of the ribbands marked on the post, line and cut out the rabbet for the after-hoods, leaving at least one inch of solid wood within them; also line out the bearding of the hoods, the measure of which is taken from the transom-moulds. The outside of the rabbet is generally straight from the lower part of the wing-transom down to the keel, where the rabbet is cut square in, the full thickness of the hooding-plank.

This being done, the *Inner-Post* must next be prepared. It should also be of good timber, and as long as to reach from the keel to the under-side of the wing-transom. It is generally tapered the fore-and-aft way, the broad end being kept downwards; the top is let one inch into the under-side of the wing-transom; it is also kept thicker than the main-post at the upper end, particularly when there is to be a raft-port left out in the stern-frame; and from the under-side of the raft-port it is thinned off from the after-edge

to the proper bearding-line. After the inner-post is fitted to the fore-edge of the main-post, fasten it with a few dowals and small bolts, and proceed to work the transoms.

Transoms.—The wing-transom should be sided and moulded the same size as the midship-floors, or 7-8ths of an inch for every two feet of the ship's extreme breadth; the transom which forms the sole of the raft-port should be about the same strength. The other transoms are commonly sided 7-8ths of the wing-transom, or one and a half inches less than it. The moulding dimension of the transoms is commonly a little more than their siding. In moulding the wing-transom (which is commonly done on its upper side, and which sometimes has a round-up the same as the 'twixt-deck beams, but oftener straight), if you intend to leave a square margin, make the transom-mould to answer a line drawn at the depth of the margin below the upper edge of the wing-transom; lay this mould on the piece of timber, and scrive it by; also scrive or mark on the piece, the centre and side-lines of the stern-post, the buttock-lines, and the cutting-lines, for the ends of the transom. Also from the points where the moulding-edge of the fashion-pieces cuts the after-edge of the transom-ends, make a straight line right along from end to end of the transom; race or score in all these marks and lines; and observe, that in moulding the transom, as much wood must be left without the mould at the *seat* or *post*, as the rake of the post gains on the breadth of the margin of the transom; for if the post has a rake of three inches to a foot, and the transoms are laid level with the keel, there would be one inch of wood awanting on the upper side of the margin of the transom, if the margin is dressed square down to four inches. When the upper side of the transom is drawn by the mould, dress or saw it square down on the after-side; strike a line along from end to end, equal to the intended breadth of the margin, from the upper edge; from this line saw the transom to its proper bevellings, and then trim and dress it perfectly fair to the same with the adze.

When it is intended to leave a square margin on the wing-transom, and the mould has been made for applying to the upper edge without the margin, you must take a straight-edged board, and draw a line parallel to one side from end to end, at the same distance from the edge as the intended deepness of the margin on the transom; next draw a line square across the board; set all the bevellings of the transom at the different buttock-lines from the end of the square line,—then the distance between the bevellings and the square line, where they are intersected by the straight line drawn parallel to the edge of the board, will be how much you are to mould within the outer edge of the mould, and for convenience these distances should be marked on the mould. When the transoms are all moulded on the upper side, you must observe that they have a sufficient curve for working to their great under-bevellings, particularly the two upper transoms have a great bevel, and when the pieces intended for these are rather straight, the deficiency of curvature must be made up by putting a good solid chock on the after-side of the transom at the breech. This chock must be well fastened with small treenails, to prevent it from splitting.

In working the transoms, I have generally found it most convenient to make the moulds for the upper sides, and fasten them on the moulding side of the timbers with two nails or gimlets, keeping the mould as far off as to make the best of the piece,

and then with the bevels to prick off both sides of the timber to the proper mould and bevelling.

Another method which I have sometimes practised, and which is approved of and practised by several, is to make all the transom-moulds for their lower sides (except that for the wing-transom), and then mould the transoms on their under side. This method is very convenient in all cases, but particularly when the timber is small, as the standing-bevels bring easier to your view the full extent of the piece. Also the lower side of the transom being shorter than the upper side, there will often be sufficient room to mark the bevel and angle of the cutting-line of the fashion-timber to a greater exactness than can be done by moulding them on the upper side, where any waste or bad timber may come in the way of the scrive.

The greatest care should be taken in correctly moulding and bevelling the transoms, otherwise it is not to be expected that the stern-frame will come together with a great degree of nicety.

Fashion-Pieces.—In procuring these, observe to seek out a good piece of timber (supposing a vessel from 300 tons downwards) of sufficient size to slit up so as to make two, *i. e.* one for each side. Their top or upper end, in particular, should be very hard and sound, as the after end of the wales and quarter-timbers must be bolted to them.

The length of the fashion-timbers is seldom limited, unless they extend down to the dead-wood, or up to the top of the work. They are commonly worked as long as the pieces can be got to answer the mould; but in all cases should extend two or three feet above the top of the wing-transom.

The moulding side of the fashion-pieces must be sawn or dressed quite fair, and exactly out of winding. They should be sided 2-3ds of the siding of the transoms, and moulded the same as the transoms. When drawing them by the mould, race in all the sir-marks, moulding edge of all the transoms, height of wales, main-breadth, &c. so far as your timber reaches; then saw and dress them neat to the bevellings, and they are then ready for putting on the transoms.

In large ships there are commonly two fashion-pieces for each side, (in order to obtain timber to answer), the lowermost piece extending to, and butting against the under side of the end of the wing-transom, or sometimes to the one under it. The lower end of the upper fashion-timber fits on to the foreside of the lower one, and makes a shifting of four or five feet below it. The upper fashion-piece is fayed close, and bolted to the fore side of the lower piece and end of the wing-transom. This method of having two fashion-timbers on each side has the double advantage of first shortening the crooked transoms, and dividing the length of the fashion-timber into two; and they are more easily obtained. The fashion-timbers are moulded and bevelled in the same manner as any of the cant-frames; and in doing so, you must be careful to race in all the sir-marks and moulding edges of the transoms.

Stern-Frame.—Having the transoms and fashion-timbers moulded, and dressed to their proper bevellings, the next operation is to join or build the stern-frame.

The stern-post being laid on blocks, with its fore side upwards, observe that it is perfectly upright, and then fasten it steady in that position. Lay the wing-transom across

at its proper station on the post; set the centre-line on the seat of the transom well with that on the post; then notice how far the transom requires to be let down, so as to bring it to its proper place; if you have one-half or three-fourths of an inch to bring it down, score it on each side of the post, and dress it out. Next fit on the inner-post, which must extend from the keel to the height of the under side of the wing-transom, or rather one inch higher; then lay on the transom, and score round the head of the inner-post; turn the transom up, and chack out this to the depth of one inch; cant the transom into its proper place, level it the cross way, and set it exactly square across the post. This being done, secure it properly in its place with a shore under each end, put firmly into the ground, and nailed to the transom, also with two stays or braces, one at each end, nailed to the top of the post and ends of the transoms.

The wing-transom being fitted properly to the post, the other transoms are all natched into the inner-post, as they may require; and being natched into their proper places, are levelled and steadied with braces from the wing-transom.

When there is to be a raft-port left out in the stern-frame, you must observe, when letting down the half-transom, to keep 2-3ds of the inner-post whole on the port-side, by snapping off so much of the end of the half-transom, in order to leave a solid backing for the hooding of the port. The transoms are now to be fastened to the post, with one bolt in each; and if the vessel is large, the wing and port-transoms are commonly fastened with two bolts in each, 1-8th of an inch less in diameter than the bolts in the other transoms.

After the transoms are all bolted to the post, the fashion-pieces are fitted on the transom-ends, and fastened with a bolt and treenail to the wing-transom ends, and only with a treenail to the ends of the other transoms. The cheek-piece for the port is then let in; it should be a very strong hard piece of timber, sided nearly as thick as the stern-post. It should stand parallel to the post, and be rabbeted one inch into the transoms at the ends, to prevent it from moving or splitting; and when it can be got deep enough the moulding way, it should have a strong lap over the inside of both transoms, and be well fastened with bolts.

When the raft-port is large, there should be a strong rider fixed along the cheek-piece, to run up as far as the cabin-deck, and down over the transoms, to 8 or 10 feet across the timbers; the rider should be well bolted to the cheek-piece, transoms, and timbers. When the cheek-piece of the port is secured, fix the transom-ends between it and the fashion-piece, letting them one inch into the cheek-piece and fashion-piece. These should be fastened with treenails and a small bolt to the cheek-piece and fashion-timber.

The stern-frame being now bound together, dress the outside all fair, and complete the cutting out of the rabbet for the hoods; also dress the inside of the transoms to the proper thickness, in order to lighten the frame as much as possible for the convenience of getting hoisted up.

For vessels of 300 tons and upwards, it is difficult to raise a sufficient purchase to hoist the stern-frame when put together. Therefore, in this case, the transoms between the wing and lower transom are taken out, after being fitted as above directed, and the

stern-post, with the wing-transom and lower transom, the inner post and fashion-timber, is hoisted up, and the transoms put into their proper place, and fastened accordingly.

Setting up the Stern-Frame.—The stern-frame being now completed, the sheers by which the stem was lifted may be shifted aft to hoist up the stern-frame. They require to be set nearly square with the after-end of the keel, or so that the purchase-block will plumb a little within the inside of the wing-transom when the frame is set up. After the sheers are brought aft, let the guys or ropes for steadying them be properly fastened; put the slings round the after-side of the post, bringing them through under the wing-transom, so that the purchase-block will hang fair with its fore side. Prepare five stout shores, one for the after part of the stern-post, one for each side, and one for each end of the wing-transom; make fast a small tackle or rope to the top of each of the fashion-timbers; likewise bore a treenail hole through the heel of the stern-post, about 4 inches aft from the outside of the rabbet, and about 10 or 12 inches up from the heel. This being done, clap hands on the purchase, and hoist up the stern-frame, guiding it fair into the mortises before easing it down; tar the mortises and tenons, then ease down the post, and put a strong bolt through the hole in the heel; pass a strong chain under the keel and up to this bolt at each side; then, with a few good wedges, set the stern-post hard down to the keel. Next set your after and side shores to the post; bring it exactly to the proper rake, and perfectly upright the side way. Of course, if the heel has been properly dressed, the stern-post will be at the proper rake, when it fayes to the keel. Set up the wing-shores, having a long square laid with its stock along the horning-line on the upper side of the wing-transom, and the blade pointing forward, it being placed at the middle-line marked on the transom; set upon either of the wing-shores, until the blade of the square points fairly out of winding with the centre-line of the keel; then set all the shores properly fast for a full due, and also keep the chain round the end of the keel until such time as the dead-woods are all on, and the heel-knee fastened.

Fitting and Bolting the Dead-woods.—The stern-frame being set up, next begin to fit the dead-woods before taking down the sheers. The dead-woods must be good pieces of timber, well free from shakes and other defects. They are generally sided the same as the keel, and the lowest piece must be of a sufficient length to cover the scarph of the keel, if near the stern. The length and depth of the dead-woods depend on the sharpness of the vessel. If the vessel is sharp aft, the lowermost piece of dead-wood may be made to answer for part of the garboard-strake for 12, 15, or 20 feet along from the post. The dead-woods should be very carefully fitted and fastened to the keel and each other with cogs or dowals; also they should have a tenon or chack into the inner-post, as shewn by *Fig.* 1, *Plate* X., K being the dead-woods, and I the inner stern-post. When a sufficient height of dead-wood is put on, the heel-knee (marked L on the plate, *Fig.* 1) is next to be sided and fitted on. This should also be a piece of good sound timber, and of sufficient length to take four or five bolts through the arm which fits against the inner stern-post, and five or six bolts through the fore-and-aft arm, the dead-wood, and keel. The bolts through the dead-woods and keel must be the same size as those through the kelson and floors; and those through

the stern-post are 1-8th smaller than those through the dead-wood and keel. I commonly cut the after-end of the dead-woods with more bevel than the rake of the inner post, and make their upper corners natch into it, and where the natch widens by letting the piece over the heads of the dowal, drive in a piece of very dry hard oak as a key. (*See Plate* X. *Fig*. 1.) When the dead-woods are fitted, they must be dressed; to do which, take the mould of the bearding-line; set it to the proper height; then draw it on the dead-wood, and dress it in the way of this line fair with the side of the keel. Again, put on the mould, and race it in, and natch in the dead-wood above this line 1½ inches in the berths of the heels of the cant-frames and timbers; then from off at nothing at the bearding-line, taper it down in a fair range to the thickness of the plank within the keel at the rabbet. Some builders are so exact as to make a mould for two or three of the cant-timber heels, purposely for dressing the dead-woods to the proper shape and hollow at the first.

Making the Frames.—Having directed how the keel, stem, stern-post, stern-frame, and dead-woods, are proceeded with, I shall next notice the moulding of the *Floors* and *Futtocks*, and the method of making the frames.

Having sided up a number of pieces of timber for floors, futtocks, &c. to the size as stated in the table of dimensions, or agreeable to the specification, commence first and mould any of the floor-timbers. Suppose we take the moulds for the timbers of an after-body frame, as frame 4. Then if the floor-mould is a single mould, *i. e.* a mould which is made to answer the floor of that frame only, lay it on the best side of the timber, and draw it by. If the floors are to be moulded on the fore side, they will have an under-bevel from the moulding side, and the first futtocks a standing-bevel from the same. In moulding the floors, you must observe that they do not become too thin on the after side, when taken to the proper bevellings. Draw the proper marks on the piece timber, the centre and side-lines of the keel; likewise the floor guide-mark, floor-sirmark, and cutting down for the height of the kelson; also note how far the floor will work without the sirmarks, as a few inches on the length of the floor-head is of great advantage in procuring the second futtocks. The end or floor-heads should never be moulded thinner than 1-3d of the thickness at the keel, when properly dressed; and the length of the natch for the chock need not exceed one and a half times the breadth or siding dimension of the floor.

The floor being now moulded, it is sawn as near to the mould and bevellings as possible, and then trimmed exactly to the mould and bevelling with the adze. The sirmarks are sawn in on the moulding-edge. You then mark the number of the frame to which the floor belongs, and proceed to mould the two first futtocks. The first futtock for the after-body frames are moulded on the after side with a standing-bevel, as the floors are moulded on the fore side. Having marked on the futtock-mould how far the floor-head extends beyond or is short of the sirmark, you will see at once whether the piece timber intended for the futtock will be long enough to work well to the mould, and to make a proper shifting or not. The first futtock should reach from within 4 or 6 inches of the keel, to 3, 4, or 5 feet above the floor-head, according as may be agreed upon in contract, being marked in the specification or on the plan.

All the first futtocks in midships will be nearly square towards their lower ends; and where they have any bevel, it will be nearly the same as the floor at the same place, only in the opposite way. The floor will have an under-bevel, the first futtock a standing-bevel, the second futtock an under-bevel, the third futtock a standing-bevel, and so on. In moulding the first futtocks, great care should be taken that they are not grain-cut, especially about the floor-heads or bilge. Rather let them be moulded a little thinner at the keel or lower end, say to 1-3d of their proper thickness, as a filling may be used at this part without being disadvantageous.

In drawing the timber by the mould, be particular in marking and scriving in all the sirmarks, as it is only by bringing these on one timber, exactly opposite to their respective marks on the other which joins alongside of it, when building the frame, that you can expect to make correct work; and should any mistake in letting the different timbers down to their proper place occur, it will throw the whole frame wrong; and if not discovered before it is put up, will cause both trouble and expense before it can be rectified.

After the first futtocks are moulded and dressed to their proper bevellings, next proceed to mould and dress the second futtocks. The lower end of the second futtock joins the floor-head; and it must, when worked to the mould, be long enough to make a proper shifting past the first futtock-head; of course you must be very careful to mark and scrive in all the sirmarks, as they are the places and directions in which the bevel must be applied; also the guide for bringing the timbers to their proper place on each other, in joining the frames and placing the ribbands. The third and fourth futtocks or top-timbers are moulded in the same manner, tracing in all the sirmarks, height of wales, upper and lower height of breadth, top-height, &c., observing to make proper shiftings, and to mould the timbers on the right sides, as all the moulding sides and sirmarks must come exactly fair and opposite to each other—the floor, second, and fourth futtocks being moulded on the same side, which may be either the after or fore side according as they are intended for the fore or after body frames; and the first and third futtocks on the opposite side to the floor and second futtocks of the same frames. When the floors and futtocks are sawn and trimmed exactly to the mould and bevellings, they are next to be put together as frames; and in like manner proceed to mould and dress exactly to the bevel the different timbers of all the other frames, being careful to mark the distinguishing characters on each. The floors are commonly sided straight, and should be as little grain-cut as possible. Those for the after-body frames are commonly moulded on their fore sides, and those for the fore-body frames on their after sides, in which case they have an under-bevel; but some builders mould the after-body floors on their after sides, and the fore-body floors on their fore sides, with a standing-bevel, making the first futtocks have an under-bevel.

The most general practice of making the floors is by one piece of timber (when it can be got of sufficient size), as represented by M M (*Fig.* 16, *Plate* X.); and the rabbet for the edge of the garboard-strake (marked 1) is cut out at the upper edge of the keel. Sometimes a filling is put on the floors, at each side of the keel, to bring the plank to slope down towards the middle of the keel, where the rabbet for the gar-

board-strake is cut out, as this is considered to make better work. But neither of these methods can be considered good; for should the keel be much chafed or cut by the vessel's rubbing on hard or rocky ground, it is certain she will become leaky. The keel being the lowermost part of a ship, it is much more exposed to receive damage by rubbing on the ground than any other part of the bottom, and should it be chafed or cut, it must be taken out at a considerable expense, and a new one put in; but this cannot be done without taking out all the floor and kelson-bolts, and one of the garboard-strakes or planks next the keel. To remedy this, and confer greater security to the ship, it has been proposed that every vessel should have 6, 8, or 10 inches of solid keel (according to her size) inside of the rabbet, and only 2 or 3 inches deep of keel below the under edge of the rabbet—the keel to be properly bolted to the floors and kelson, and a false one of 6, 8, or 10 inches deep, brought on below the main keel, with dowals and sprig-bolts; so that should this piece be chafed or cut, the main keel would still be entire and tight, and the under keel could be taken off and another piece put on, at a small expense. In this case, the floors would require to have fillings, but it would enable the builder to make his floors of straighter timber; it would also allow larger limber-holes to be made without wounding the floor-timbers; the limbers would also contain more water before it came up to the cargo.* As this is an improvement of great advantage to shipowners, I have drawn on *Plate* X. a part of the floor, and section of the keel, kelson, and fillings (*see Fig.*35); M M is part of a floor-timber crossing the main keel marked A, T the kelson, F the fillings, B the false or lower keel, C the dowal, P and P′ the garboard-strake and bottom plank, and *d* the timbers.

Joining the Frames.—The operation of joining together the different timber in constructing the frames, or the methods taken for that purpose, may vary a little according to the custom of the place; but I shall give directions for joining the frames, agreeable to the method commonly practised in Scotland, and in some parts of England. Take the floor-timber, and lay it with its moulding-side up, on three pieces of wood or edging, so that it may lie as far off the ground that a chain may be got through below it. Make four stakes, and drive them into the ground, two on the inside and two on the outside of the floor, so as to keep it from shifting. Procure a plank, equal in length to the depth of the frame; place its end against the breech of the floor, laying a block of wood under it, so as to bring it level with the upper side of the floor, horning the plank vertical from the floor-sirmarks, *i. e.* to make it perpendicular to the floor; also strike a line in the plank, horning it quite perpendicularly from the floor, which line will represent the centre-line of the frame, from which the half-breadth battens are to measure the breadth of the frame. The plank must therefore be kept fast in its place, by driving a few stakes into the ground on each side. The centre-line of the frame being thus erected, lay the second futtocks down on the ground, with a few

* James Horsburgh, Esq. Pittenweem (late shipbuilder, Calcutta), a gentleman of great experience, first suggested this improvement, and in communicating it to the author of this work, says "This method I have practised with great success, and as a proof of its advantages—a ship that I built in this manner got on the rocks at the island of Ceylon, and chafed away about 14 feet of her keel, quite up to the plank, and also four feet of the fore part of her stem; yet she came in that state to Calcutta, a distance of 1000 miles, without making much water."

pieces of edging under them; bring their lower ends to butt on the floor-heads; then lay the first futtock-mould on the floor, making its edge fair with the moulding-edge of the floor; also observe that the sirmarks of the mould are opposite to those on the floor. The mould may then be held in this position, and the futtock laid fair with it, and observe that the sirmarks on the futtocks are opposite those on the mould; to bring which to agree exactly, you will perhaps have to cut a small thing off the heel of the timber, or run a saw-carph between the floor-head and heel of the futtock, and then give it a blow down close to the floor-head; and in this manner you may have to cut and set them down two or three times, until you get the sirmarks in the futtock to come exactly to those on the mould. If the second futtock reach as far up as the lower height of breadth, you may take the half-breadth batten, and from the centre-line set the frame to the exact breadth. When the futtocks are lying fair with the floor, and out of winding with each other, fasten them steady by a few stakes. Lift off the first futtock-mould, and lay the first futtock on the floor and part of the second futtock, laying it so that all the sirmarks on the first futtocks agree with those on the floor and second futtock. If the sides of the timbers are to be kept a little separate, a piece of 2½-inch plank must be put between the floor and first futtock, at the place where you intend to bolt through; and to prevent this piece from splitting by the bolt, it should be let into the floor and futtock, about 3-4ths of an inch. But if the siding of the timbers is large, it is as well to fit them close down, so that they are better united; sometimes they are fitted together with dowals, when a real good job is wanted, but this in general may be dispensed with. Next lay the fourth futtock or top-timber to the end of the second futtock, and set it to its proper breadth by the half-breadth batten; then lay on the third futtock-mould, having its respective sirmarks agreeing with those on the second futtock; hold it fast in this position; observe if the top-timber requires to be let down, to bring the sirmarks on the same, to agree with those on the upper end of the mould, and when you have brought these to agree, and tried the half-breadth batten again, you may fix the timber in its place, and lay on the third futtock, butting its lower end to the head of the first futtock, laying the moulding edges of all the timbers as fair with one another as possible. The third futtock and short top-timber being laid fair in their proper places, and both sides of the frame set to the exact half-breadth, clap a few stout chains round them, and set all fast with wedges, observing that in setting the wedges you do not shift the timbers from their places; then proceed to bore the bolt-holes on each side of the joints of the timbers, and fasten the frame together, either as a whole or only in pieces, as may be thought most convenient for getting them erected on the keel. For vessels below 100 tons, the frames may be all fastened together on the ground; but for vessels from 100 to 300 tons, the futtocks are fastened together, and the floors put across the keel and levelled, before the first futtock is fastened to it. In this case, you bolt all the futtocks together, and bore the bolt-holes through the first futtock and floor; also a treenail hole through between the two bolt-holes. For large vessels, only the first and second, and the third and fourth futtocks are bolted together on the ground; but the bolt-holes are all bored, and the bolts driven when the frames are set up; the frame-timbers are commonly bolted with ⅞-inch square iron.

The frame being thus completed on the ground, you must prepare the cross-pawl or baulk (this is merely a piece of fir deal or a plank nailed across the frame to keep it to the proper breadth) by cutting it to the exact breadth of the frame at the place where it is to be put across, which is commonly at the top-height of breadth, or top-height; find its middle, and make a natch or saw-carph at the same; lay it across the frame, and bore two nail holes, and enter the nails a short way through the cross-baulk into the timber, that they may be the easier entered when the frame is set up; take off the baulk or cross-pawl, mark the distinguishing character of the frame on it; it may then be laid aside where it will not be broken; also the frame may either be left lying or taken separate, to allow room for making the others, or left lying where made, until they are all ready for setting up.

Having now described how one frame is put together, the others are done in the same manner, and the whole frames made and joined together, as now directed, before the floors are put across the keel.

Cant-Frames.—These frames are put together in the same manner as the others, only they have no floor-timber (being so far forward and aft in the ship.) They have, however, a half-floor reaching from the foot of the second futtock to the heel of the first futtock. It requires very correct work, in setting off the exact height and bevel of the heels of the cants, to make them fit against the dead-woods, and keep the frame to the exact height. The bevels of the heels of the cants are procured from the draft, or the lines in the mould-loft. The best method is to natch them into the dead-wood, dressing the natch perpendicularly up and parallel with the keel; so that the bevelling of the heels will be as much standing or under as the frame cants, either forward or aft, according to the situation of its moulding-edge. Thus if the moulding-edge of a cant-timber in the after part of the ship be the after side of that timber, the bevel of the heel will be a standing-bevel, more or less, according to the degree of cant aft; but if the moulding-edge be the fore side of the timber, the bevel will be as much an under-bevel. The bevel of the end of the timber is taken from a vertical line to the form of the bearding-line on which they stand; and the cross-pawl or baulk is marked to the square breadth.

Putting up the Frames.—The stem, stern-post, and dead-woods being all put up, properly adjusted and fastened, and the frames made, and every thing ready, the floors must first be put across the keel, horned and levelled. They must be let down to their proper height from the base-line or rabbet, by setting the given height from the cutting-down line. There are different methods of letting down the floors. Some set the rising of every floor on a board; and when fitting them down to the keel, stretch a line across betwixt the sirmarks from one side of the floor to the other, and then let them down until the rising as marked in the board, or rising-staff, agree with the line. This is a very correct and easy method.

When the keel is higher than is required above the rabbet, the floors must be scored or let down into it; in doing which, you must take great care to have the floors properly levelled and set square across the keel, by horning them from the centre-line on the keel to the sirmarks of the floor, keeping the centre-line on the floor well with that

on the keel. In this manner the framing floors may all be put on and levelled, and a shore put under each, drove firmly into the ground, and nailed to the side of the floor, but not to the moulding side, as it would come in the way of the futtock. After the floors are levelled and horned, square across the keel. They must be steadied with a span or brace until they are bolted to the keel, which must next be done.

Supposing every other floor to be a frame, the intermediate floors are to be put in after the ribbands are run. The frame floor-timbers being all levelled and bolted to the keel,* the half frames, *i. e.* the first futtock, and the others which are joined to it, are next to be brought to their respective sides, and placed with the heel of the first futtocks between the floors to which they belong, so that the moulding sides of the futtocks shall come to the moulding sides of their respective floors. This being done, you next procure a pair of stoutish sheers, but not too heavy for being easily shifted; have three tackles attached to the sheers, a stoutish one on each side, and a small one for hoisting up the cross spales or baulks; next prepare a number of shores of different lengths, cleats, wedges, frame-bolts, &c. &c.; then cant the frame on its back, with the futtock close against the floor to which it belongs. Observe that the treenail hole (bored between the bolts when making the frames) is fair with that through the floor; then reeve a stout bolt or crow through both timbers; clap on your strap or chain for hooking the tackle to; set on the tackle, and hoist up the half-frames on each side of the ship equally; and as soon as the moulding-edge of the futtock comes fair with that of the floor, observe if your bolt-holes are fair, and immediately drive in the bolts. To steady the top of the frame, you should have a guy-rope from the top-timber. When the bolts are driven in through the floor and futtock, nail a cleat on the frame about the height of the lower side of the wales, also one on the after-side of the frame; place a shore up to each of these cleats, and hoist up the cross-spall. If the frame is either too wide or too narrow, you must set upon or slack the side-shore, until you bring it so that the nails in the cross-spall or baulk enter the holes in the timber; then drive them firmly in. Next set the frame upright, that is, square of the keel, and out of winding; steady it by a brace from the inside of the stem (it being supposed the fore-frame which is first set up); then hang a plumb-line from the centre mark in the cross-baulk, and set the frame up by the side-shores, until the point of the plummet become vertical to the centre-line of the keel; then set all the shores fast, and proceed with the next frame in the same manner, until they are all set up, cant-frames and all together. When they are all put up in this manner, set a few hands to overhaul them, and see that they are all standing quite plumb, which may be observed by sitting on the wing-transom, and casting your eye across the baulks; for if they are all plumb, the centre-line marked on them will appear perfectly straight from the centre-line on the stern-post to that on the inside of the stem, and the baulks will appear completely out of winding with each other. Also observe that the frames are all set square across the ship, and at equal distances from each other at the top. This should be particularly attended to, because if they are not regularly spaced, it becomes difficult to get the

* For the size of these bolts, &c. see Table of Dimensions.

stanchions, ports, or any other of the deck work which requires uniformity, in their proper place, when you come to finish; besides, it in a certain degree alters the model of the ship when the frames are not set very accurately in the places for which they were intended.

In several parts of England, they bolt the first, second, and third futtocks together, leaving the heel of the second futtock a very little longer than the exact length. Place the floors on the keel; let them down, and level them in the same manner as we have now described. A stout ribband is next put round at the floor-sirmark, and well shored up; the half-frames are then hoisted up, and placed with the first futtock resting on the ribband; the back of the frame is then plumbed, and made to stand perpendicular to the keel the side way; it is then set to the half-breadth by the half-breadth batten, or by measuring from a middle line on the keel, or a line stretched from the centre-line of the stem to the centre-line of the stern-post; then as much is cut off the heel of the second futtock as will allow it to come down so far that the sirmarks agree with those on the floor. The frame is then properly shored, the first futtock bolted to the floor, and brought out of winding, cross-spauled, and set upright by the plumb-line from the centre-mark on the cross-spales.

Running the Ribbands.—The frames being all set fair, the ribbands are now to be put round, for supporting the frames and carrying the intermediate timbers, shewing the form of the work, &c. The ribbands for the middle of the ship (supposing a vessel of 200 tons) should be about 4 inches broad, and 3 or 3½ inches thick, and of as great a length as possible, being fine clean pieces of edging; but those which reach from the fore-frame to the stem should be worked from circular pieces of timber to the form of the diagonal ribband-lines and harpins, so that the rounding of the bow may be kept to its proper curvature.

When the *guide* and *floor-head ribbands* are put round, they must be shored before the others, and great care taken that the bottom of the ship is quite level. If this be neglected, it produces a very serious evil, insomuch that when the vessel is launched, she will not swim upright, but heel over to one side, and consequently require more ballast in the one side than the other; but notwithstanding the manner she is loaded, she will neither sail nor work so well on the one tack as on the other; therefore it should be particularly observed that the bottom is level across from the floor-sirmarks on one side to those of the other. If the ship is to be full set with timber before the bilge-plank are worked too, these ribbands should be shored at the distance of every 4 feet from stem to stern. In many places it is the custom, as soon as the floors are in, to work two of the bilge-strakes in place of ribbands, and set the proper shores to stand during the whole time of building. When the guide and bilge-ribbands are put round, the staging is next put up, and all the other ribbands are put round, *i. e.* one at the heads of the first and second futtocks, one at the under side of the main-wales at the upper height of main-breadth, and one at the top-height of the timbers. All the ribbands on the flat of the side should be made perfectly fair, not only to the round of the side, but also to the intended sheer, as near as possible; they should also be stronger than those pieces which have to bend round the bow or quarters. The three upper

ribbands should be joined together at their ends by a short scarph; the two upper ones should extend as far aft as the after-side of the quarter-timbers; and as these ribbands are run before the quarter-timbers are up, their ends which extend beyond the fashion-timbers must be shored up to the proper sheer, and set to the exact breadth, with a span across, having a centre or middle line marked on it, and steadied by two angular braces from the stern-post.

The ribbands are fastened to the frames with large round-pointed nails, called rib-band-nails; they have a large round head, and are drove through a small piece of hard wood about 3 or 4 inches square, through which a hole is bored sufficiently large to receive the nail. These pieces are called button-cleats, or hudgicks; but for large vessels, iron rings of a flat form are used. The use of driving the nail through these and the hudgicks is to allow the ribbands to be wedged off without splitting, or breaking the nails into the timber. The ribband at the lower side of the wales should be properly shored, but particularly under the luff of the bow and quarters.

The Filling-in Timbers.—When the ribbands are run, the filling-in timbers are next to be proceeded with. The intermediate floors between the frames must be moulded and put in first, immediately after which the kelsons are to be fitted.

We have considered every other floor to be made a frame, which is the most common case, and is found to answer very well; but in building a fine vessel, I would recommend that the timbers be all properly joined together, so as to make the whole frames, fore and aft, having only a few timbers to fill in, in the way of the luff of the bow and quarters after the frames are up. I would also make the heel of every alternate first futtock to cross the keel, first on the one side, and the futtock of the next frame to cross the keel towards the other side of the vessel. They may either be scarphed or fastened to the futtocks on the opposite sides by a short scarph or a stout chock. In building steam-boats, whose bottoms are commonly more flat than sailing vessels, in order to form a proper bed for the engines, and cause the vessel to draw little water, their bilges being suddenly rounded up to meet the side which is commonly upright, it is difficult to procure natural crooks to form the first and second futtocks without being grain-cut. And as these vessels have a good breadth of the floor, the first futtock requires to be very long, to make a proper shifting past the floor-head, and extend down to the side of the keel. To abate this, and make the boat stiffer in the way of the engine-room, the first futtocks may be moulded short of the keel two or three feet, so as they have a proper shift past the floor-head. To assist the conversion still farther, the inside of the heels of the futtock may run aft to about 3 or 4 inches thick, and form a scarph about 18 inches or two feet long. When this is done, a half-floor is laid across and fitted to answer the scarphs of the heels of the futtocks; in this case, as the usual run for the water will be filled up, a circular groove may be cut along the upper side of the keel, running from about the fore-mast to the place of the pumps aft; also a little may be taken out of the seat of the floors to enlarge the water-course. When the water-run is made in this manner, care must be taken to drive the floor and kelson-bolts clear of it, and a copper chain must be rove down through an air-hole through the kelson forward under the floors and along the water-course, and up through the kelson aft. If the chain is not at hand when the floors are put in, a

piece of rope must be laid along through the water-course, by which to haul the copper chain through afterwards. The chain must be somewhat longer than merely to reach through the whole length of the water-course, in order that it may be hauled along fore-and-aft, to clear any stoppage that might obstruct the run of the water to the pumps. But perhaps it is the best way in this case to form a water-run or limbers above the top of the timbers altogether, either by canting the inner-edge of the limber-strake up against the sides of the keelson, so that a water-course or limbers is formed between the side of the keelson and the top of the floors.

But to return to the general method of proceeding. When the filling-in floors are all put in, the keelsons must be got in and fitted, taking care to have the scarphs properly shifted over those of the keel. The scarphs of the keelson should be equal in length to six times the deepness of the pieces; they should be hook-scarphed and the points left 3 or 4 inches thick. When you have two heights of pieces to make up the proper size of the keelson, the scarphs of the lower piece must be properly secured, the same as if no other piece was to cover them. If this be not attended to, you will lose a great part of that strength you expected to have by two heights of timber. A few small bolts should also be driven through the lower piece into the floors to keep it close down until the upper pieces are all fitted, which must run from the heel-knee (to which it must be bolted) to the apron of the stem.

In laying on the upper pieces, observe to place the scarphs clear of the scarphs of the keel and the under pieces of the keelson; likewise observe not to natch in the scarphs of the upper pieces too deep, or you will reduce its strength very much in respect to the transverse strains. When the keelsons are all fitted, they must be bolted down through both pieces, every other floor and the keel.

When the keelsons are put in, and the bottom all secured, go on regularly with the filling-in timbers, also with fixing the knight-head timbers and the hawse-timbers, as you require room clear of the other timbers of the bow, in order to get the knight-head and hawse-timbers properly bolted, taking particular care to place these bolts clear of the hawse-holes.

The stern-timbers should also be got on with as speedily as possible, for as it requires considerable time to get them placed and fitted properly, the planking may be stopped for a while on this account.

Of the stern-timbers, the two outside ones are the principal, and are those which form the quarters of the vessel, wherefore they are called the quarter-timbers, and are the first of the stern-timbers that are set up.

Working the Quarter and Stern-timbers.—We have described the method of laying down the mould and bevels of the quarter-timbers, which if the reader fully understand, he will have no difficulty in moulding and working the timber to its true shape. In page 204, and *Plate* XXIV. we have shewn how to construct a mould to answer for both quarter-timbers, by being hinged or jointed in a peculiar manner; therefore, proceeding on the supposition that the quarter-timber has been laid down in the floor of the mould-loft, and the mould made as directed, we have only to take notice of the method of applying it, and dressing the timber to the proper bevellings.

Having your fore-and-aft mould and thwartship-mould made, proceed to look out a suitable piece for the quarter-timber, and endeavour to have it all in one piece if possible, if the vessel is under 300 tons; but when larger, it is more convenient to find two pieces for this purpose, and to scarph them together; however, it requires greater nicety in working and bevelling the timbers in this case, as the pieces must be rough-moulded and bevelled before they can be scarphed together. But supposing you have procured proper pieces of timber to make the quarter-timbers, first take one of them and rough-mould it to the fore-and-aft mould, and saw it to the bevellings the thwartship way as near as possible; next proceed to line it to the fore-and-aft or moulding dimension, making an allowance on the thickness for dressing it exactly to the bevellings of the round aft of the stern. There will be one spot in the counter-part of the timber which has no bevelling, but is quite square across, being parallel to the transverse line of the vessel; therefore this becomes of great importance, as all the other bevellings, both above and below, side way and thwartship way, may be winded from it, which is a material point in the operation.

In laying down the quarter-timber on the plan of the vessel, *Plate* XXIV. page 204, I have mentioned this circumstance, and marked the spot referred to on the timber by the letter *d*, corresponding to the extreme of the horizontal section, whose plane is represented by the straight line marked ×——× *Figs*. 4 and 5. Then, suppose the quarter-timber to be dressed square at the spot *d*, which comes exactly where a straight line would cross the counter from one quarter-timber to the other, and touch the hollow of the stern-timbers in crossing (at the after part of the rudder-case), exactly perpendicular to the middle line of the ship, and perfectly horizontal. This much being done, you next proceed and take the bevellings from the bevel-board, according to the round aft of the stern at the different heights of the sirmarks, and applying the stock of the bevel to the timber, dress it in at that spot, until the blade of the bevel becomes out of winding with that of another bevel set to the same bevelling, and applied at the square part of the timber (as before mentioned), which is supposing that the bevellings have been taken from a line parallel to the middle line of the ship.

When you have dressed the timber to the proper bevelling at these spots, line it fair, and dress it to the after-round of the stern. Take from the stern-plan the round-up of the knuckle of the quarter-timbers, at the lower edge of the first and second counter or arch-board. This round will also be produced on the timber by the working of the bevel of the parts above and below the knuckle; but it will be farther directed, by taking the proper rise from the plan, from a vertical line, in which case the stock of the bevel must be applied on the side of the timber, and brought out of winding with the blade of a square, the stock of which is applied at the square part of the timber, when the blade of the bevel will lie in the direction of the round-up of the knuckle of the quarter-timber. When the timber is thus moulded and dressed to the fore-and-aft mould, and the round aft of the stern, you may next apply the side-mould, which is jointed at the knuckle, so as to fold to the fore-and-aft kneeing of the timber, while its edge is the mould the side-way of the quarter-timber. I have before explained (p. 205) how this mould is laid down and applied to the timber, as represented by *Fig.*

6, *Plate* XXIV.) When the timber is drawn by this mould, it is dressed exactly to the bevellings the side way, so as to suit the round of the quarters of the ship, and the bevellings are applied in the same manner as those for the round aft of the stern, *i. e.* by looking them out of winding with a bevel applied to the square part of the timber at the letter *d.*

Stern-timbers.—In regard to working the stern-timbers, little need be said, as the operation is very simple. The mould of the stern-timbers will be very nearly the same as the fore-and-aft mould of the quarter-timbers. The stern-timbers are sided straight from top to bottom, but tapered towards the top, and as they are sided straight and square, the round aft of the stern is easily given them. In vessels of any considerable size, they are commonly in two pieces, scarphed together above the arch-board and below the same, to break-butt or make shift with the scarphs of each other.

Putting up the Stern and Quarter-timbers.—When the stern and quarter-timbers are thus prepared, you must proceed to put them up in nearly the following manner:—Procure a good clean spar or pole, of sufficient length to reach from the ground to about 6 or 8 feet above the main gunwale at the stern-post; set it up abaft the wing-transom, in a proper position for fixing a block and tackle at its top for hoisting up the quarter-timber to its place; secure the pole by a lashing to the wing-transom; have a good tackle fast to the top of the pole or daddic (as it is also named); fix a screw-bolt into the inside of the quarter-timber, for hooking the tackle to. Then every thing being right, hoist up the quarter-timber, keeping it inside of the top-ribbands; when it is hoisted up, rest its heel on the transom, and set it to the proper rake aft, as measured from the plan of the vessel; and set aft, from the same frame from which you measured from on the plan, the place where the after edge of the timber should come to on the top ribband, which is set to the exact breadth by the cross-ribband, and steadied by the spar pieces from the stern-post. The quarter-timbers for the other side may also be got up at the same time. When the timber is steadied to the proper rake aft, you must take a fitting mark to make the heel of the timber fit exactly to the wing-transom, and against the after side of the fashion-timber. When the mark has been taken, raise the timber up with the tackle, and dress its heel to the proper form, after which, it is again to be tried on to its place, and if it fit well, it is to be secured. When they are properly placed and fitted, drive a stout nail through the top-ribbands into the timber, and steady them to their proper breadth at the top, by a brace from the stern-post. Put a stout bolt through their heels into the fashion-timber; set up a shore from the ground against the after-side of the timber, a little below the knuckle, to be clear of the arch-board. When certain that the quarter-timbers are placed with their exact rake aft, and to the proper breadth at the top, according to the intended tumble-home of the quarters of the vessel, fit a stout knee on the wing-transom, the other arm against the inside of the quarter-timber; there should also be a stout piece of ribband nailed across the counter, from the one quarter-timber to the other, quite straight and level, about the after side of the rudder-case, this part of the stern being quite straight, having no back-round. When the quarter-timbers are thus fastened by the knees on the wing-transom, next fit and bolt a piece of good solid timber close to each side of the

stern-post, and shaped to the curve of the rabbet of the hoods, extending from the wing-transom (into which its end must be chacked one inch) up to the rudder-case.

Arch-board.—The arch-board may now be put up, worked to the proper round, and the mouldings wrought on it (supposing a vessel of 300 tons); set its lower edge fair with the knuckle of the quarter-timbers, nailing it to the same; after which, you have only to shore it to the back round of the stern, by means of a short spar or shore set against the after-side of the stern-post.

But the easiest and most correct method is to have a straight piece of edging set up from the side of the stern-post, similar to a stern-timber, giving it the intended rake and back-round of the stern, looking it out of winding with the quarter-timbers. Steadying it in this position by two braces from the stern-post, you may then put across two ribbands, worked to the circle of the back-round of the stern, the one to answer the top, and the other just a little clear of the arch-board, or whatever stationary work you intend to put up first, which is commonly the arch-board, and which is nailed to each of the quarter-timbers, and to the piece edging set up from the stern-post, which serves to support the arch-board and give it the proper cant. But before the arch-board is nailed to the quarter-timbers, observe that it is perfectly level. To ascertain which, first find the exact middle of the ship on the upper or lower edge of the arch-board, by laying a long straight-edged batten in a fore-and-aft direction, the one end on the arch-board and the other against one side of the stern-post, then shifting its after end until it point fair for the same side of the ship's stem. Then, of course, if you measure from the batten to the centre-line of the stern-post, and set that distance from the batten on the arch-board, you will have the centre-line of the vessel marked on the arch-board. If this mark agrees exactly with the centre of the arch-board, measured from the outside of the one quarter-timber to that of the other, it is a proof that they are fair set.

Having the middle-line of the ship marked on the arch-board, measure from the same, along its upper edge, an equal distance on each side, perhaps six or eight feet, according to the breadth of the stern; then from these equidistant spots, stretch a line across, and set the end of the arch-board a little up or down until this line becomes out of winding with another line stretched level across the frames. It may also be levelled by driving in the nails at the equidistant spots, to rest the edge of a straight parallel batten, on which a level may be placed, and the arch-board properly adjusted. But if the quarter-timbers are set, so that the one is not the least thing farther aft than the other, and the wing-transom perfectly square and level, as should always be the case, you have only to measure both ends of the arch-board, or the straight line struck on it from the equidistant spots, from the horning-line on the top of the wing-transom, and the arch-board raised or shifted, so as to lie perfectly level. These measurements and levellings should be very carefully done, as the smallest mistake or variation from the true level will be easily observed when the stern is finished.

Having the arch-board, and whatever other railings you mean to employ, properly adjusted, set a shore up from the ground, to support the middle of the arch-board and carry the weight of the stern-timbers; also bind in the arch-board and the other ribbands by means of a brace to the stern-post, to prevent them acquiring a greater round

aft than is desired. This being done, you may then proceed and divide the stern at the top-ribband and arch-board, for the proper berthing of the stern-timbers, whose moulds may now be tried in their respective places, and the bevellings taken at the same time. The stern-timbers are then moulded and dressed to the bevellings, after which they are hoisted up, and put into their places. In dressing these timbers, their heels should be worked so as to fay on the top of the wing-transom, having also a lap or chack, so as to come on the after-side of the transom as far down as the bearding-line of the margin; likewise the other part of the heel of the stern-timber should be let 1½ inches down into the top of the transom, and be bolted down through the heel of the timber into the transom. By natching the fore part of the heel of the timber into the transom, it will be prevented from splitting with the bolt, or from starting forward, and splitting the back lap, which comes down over the margin of the transom.

Half-stern and Counter-timbers.—When the stern-timbers are placed, the half-stern timbers are next put in; these reach from the wing-transom up to the arch-board; and between these and the others, the spaces may be filled up with pieces worked to the curve of the counter, reaching from the wing-transom to about the height of the straight ribband before mentioned. When this is done, take a piece of good sound timber, and fit it down to the top of the wing-transom, reaching between the ends of the knees of the quarter-timbers, and against the heels of the stern or counter-timbers; it must then be well bolted down to the tramsom, through the stern-post and the heels of the principal stern-timbers. A false transom is often fitted on the inside of the counter and stern-timbers, as high above the wing-transom as can be got for the stern-post, into which it must be natched, and also a natch into the false-transom for the stern-post. This piece should have a stout bolt through the stern-post; it is put in for giving strength to the counter, and for receiving the bolts of the butts of the bottom-planks, which run up into the counter. The false transom is farther secured by having an iron-knee at each end, bolted to the ship's quarters after the ceiling planks are on.

(*Note.*—For the dimensions of these pieces, and of the iron knees, bolts, &c. see Table of Dimensions.)

Planking.—The timbers of the stern, and all the other filling-in timbers, being completed, and the whole of the frame of the vessel filled up, the outside of the timbers, from the keel to the gunwale, and from stem to stern, are next to be dressed fair with each other, so that the plank may fay solidly against them, which is called the sembeling of the plank. If this part of the work is done in a careless manner, the ship will be deficient in point of strength, even although every other part of the work be executed in the most correct manner.

In many places, both in England and Scotland, the timbers are only dressed fair progressively as the planking goes on. But it is certainly the best way to dress the ship all over before the planking is begun with, as she may thus be dressed much fairer, both in the fore-and-aft and up-and-down direction; this method will also be of the greatest advantage in the seasoning of the timber, the rapid decay of which is chiefly attributed to the joining closely together two surfaces, either of which is damp or unseasoned.

The planking is a very important part of the work—perhaps the most important of the whole; and no little ingenuity is displayed in the proper arrangement of the different kinds of thick-stuff, &c., and in the shifts and dispositions of the butts.

Various circumstances regulate the commencement of this operation, such as the state of forwardness of other parts of the work, the nature and dimensions of the plank, the season of the year, or the time or expedition with which the vessel is to be finished.

Before commencing, we must consult the draft of the vessel for the position and heights of the different particular strakes of thick-stuff.

I have shewn (*Plate* XXI. and p. 217) the methods of expanding the bottom and shifting the butts of the planks. Accordingly, I have only to describe the most correct and general method of managing this part of the work in practice.

The first thing to be done is to take a piece of thin fir board of a sufficient length to hold the vessel on a half-inch scale. When the board is planed smooth, mark on it the length of the keel, and station of all the frames, squaring lines across to represent the same; then proceed and measure the round of the vessel's bottom from the rabbet of the keel up to the lower edge of the bends on several of the frames; then set this off from the line of the keel on their respective frames on your board; also measure the distance from the keel to the floor and third ribbands, and likewise mark these distances on their respective frames on the planking-board, and the more measurements you take the better; indeed, they should be taken at every frame to be exact, for by so doing you will have the more spots on the board through which to draw the ribband-lines exactly as they are run on the ship. Having thus traced the ribband-lines, and the line of the lower edge of the bends from the foremost to the aftermost square frame, next take the rule or line, and measure from the foremost frame round the lower harpin to the rabbet of the stem, and also from the same frame round to the rabbet of the stem on the different diagonals; and taking half inches for feet, set these distances from the foremost square frame on the planking-board forward in the direction of the curve of the pending or snying of the bends and the different ribbands; and then, from the place on the keel-line where the rabbet of the stem joins that of the keel, draw the curve of the rabbet of the stem, passing up through these spots. To prove if it be nearly correct, measure from the same spot where the rabbet of the stem joins that of the keel, up round the rabbet to the place where the different ribband-lines and lower edge of the wales-harpin meet the rabbet of the stem; then, if it is found necessary, alter the rake of the stem on the board, or lower the place of the ribband-lines at the same, and bring all these to agree as nearly as possible. In like manner, proceed to set off the stern-post on your board, by measuring from the aftermost square frame on the different ribband-lines round to the rabbet of the stern-post. When you have got the stern-post also drawn on the planking-board, to prove if it and the curve of the stem are correct, measure the length of the third ribband on the vessel round from the rabbet of the stem to that of the stern-post, and then try if the third ribband on your board agree; if not, then some slight alteration of the rake of the stem or stern-post must be made.

Also, upon another or the same board may be laid down the upper part of the vessel

above the lower edge of the wales to the expanded length. The surface of the bottom and upper works of the vessel being thus laid off on the board, the next thing to be done, before you can mark the position of the butts, is to ascertain the lengths of the plank to be used; therefore you must measure the length of a number of them, taking it only as far as they will work to the proper breadth, clear of all defects, such as shakes, sapwood, or the like, and arrange the lengths and thickness into different columns in your note-book.

Having thus obtained the length and breadths of the planks, proceed to draw the different strakes on the board from stem to stern-post, making their breadths regular by dividing the distances from the rabbet of the keel up to the lower edge of the wales on the different frames, as equally as possible. You are then ready to mark the shiftings and position of the butts, as before directed in p. 221, and *Plate* XXI. If the planks are of a variety of lengths, it will require consideration to get the butts so placed as to make good work with little waste material. In setting them off, mark the length of each plank on it at the same time that you mark the butts, which will enable you to see what number of the different lengths will be required. By this method of having all the butts marked on a board, to be used in the yard, you will be enabled to make good work, save materials, and carry on the planking with expedition.

Setting off the exact Height and Sheer of the Wales.—Having a stage round the vessel at a convenient height for putting on the wales, it will be necessary to proceed, in the first place, to set off their exact height and sheer, as the ribband which is commonly run round at their lower edge may perhaps be incorrect; for this being merely a temporary thing, and only intended to steady the frames of the vessel, it may not have been so exactly set to the height and fair sheer as to be a sufficient guide for placing and sheering the bends, which are to be permanent, and if possible to retain their original sheer while the vessel lasts. To place the bends to their exact height and sheer, take two or three battens of a good length, about 2 inches broad and 3-4ths of an inch thick; the battens must extend round the vessel from stem to stern-post. (A rope of about 5-8ths or 3-4ths of an inch in diameter is sometimes used in place of the battens, but it does not answer the purpose nearly so well.) In preparing battens for this purpose, seek out clean pieces of fir or ash, and when they are planed fair and smooth, they should be painted or stained black, that they may then shew more conspicuously when run round the vessel on the white timbers, and thus enable you to detect any unfairness in the sheer to which they are set; also the ends of the battens should be made to fit into each other, so that, when put round, their butts will be fair the edge-way.

The battens are to be put along the side and round the bow, to the exact height of the wales, as marked on the frames, or otherwise determined. Fix them to the side with small cleats and batten-nails drove into the timber, either above or below the batten, in such a manner that the batten may be raised or lowered at pleasure. The battens may be put round at either the upper or lower part of the wales, as thought most convenient, in order to obtain a complete sheer on the upper works of the vessel. For this purpose, I would recommend them to be put round at the upper edge of the wales,

as there will be less twist at this place than at their lower part; and of course the curve of the battens may be viewed to more advantage, and easier corrected, by a straight line, which may be stretched along the side, and the curve of the wales set off. Thus, suppose we take the curve of the sheer for any considerable length, say 32 or 40 feet, on which the curve may be 4 or 6 inches; then, as it is known in practical geometry (*see* the first chapter of the Introduction, p. 15), that on half that length there will only be one fourth of the sheer; therefore, by taking 16 or 20 feet of that length accordingly, and drawing a line to a perfect straight, forming a chord to this length of the batten, you will immediately be able to determine whether the battens are set to the regular curve or not. In this manner, different parts of the batten, all along the side, may be corrected and brought to the uniform curve as desired, from the quarter-timber right forward to near the foremost square frame, where it will rise a little quicker, and continue to increase the curvature according to the rounding of the bow from the foremost frame (or the one immediately abaft it) to the rabbet of the stem, where it must be as high above the common sheer as a regular, fair, uniform curve, equal to that of the sheer of the ship's side, would be, if projected straight forward from the foremost square frame (on a vertical plane parallel to the ship's side), to a length equal to the rounding-in of the bow upon the horizontal section, as before explained at page 189. (In connexion with which, see the method of setting off the sheer of a vessel from a straight line along the side, page 15.)

Having the sheer adjusted and set fair on one side, race it in by the edge of the batten, and also mark it on the sides of the frame-timbers, which may become of service in setting off the sheer or height of some of the inside work, levellings, or the like. Next proceed to set off the bends on the other side of the ship, and to make both sides equally high and level, and out of winding; stretch a line or stout batten across some of the midship-frames, and set it perfectly level, keeping the one end exactly at the mark of the bends as sheered, and raising the other up or down a little, until it is quite level, when it may be fixed, and several other lines stretched across before and abaft it, and brought exactly out of winding; put the battens round to these lines, fair them to the exact sheer as you did the first side, and race them in upon the timbers. The next thing to be done is to line out upon the timbers the breadth of the strakes of the wales, placng their butts as marked upon the planking-board. But observe, in lining out these strakes, to strike the line as much higher above the proper height, which is raced in upon the timbers, as what the thickness of the plank will cant down at its outer edge, in bending and twisting round the plane of the timbers, to which they must fay as closely as possible. If this is not carefully attended to, the outer edges of the seams of the bends about the quarters will be unfair, even although their inner edges are running to the exact sheer. This will easily appear when your eye passes the upright part of the side either towards the bow or stern, when the work will immediately appear to diverge from the uniform curve which it should exhibit when finished. The sheer and breadth of the wales being now set off, and every thing ready for planking, a few strakes on each bilge must be put round; beginning two or three strakes below the floor-sirmarks, work upwards, and when three or four strakes are on, set up the

bilge-shores for a full due, to stand during the time of building. About the same time, work on the limber-strakes, and bolt them to the floor and heels of the first futtocks. In planking the bilge, pay particular attention to level the bottom across, and set the bilge-shores accordingly. When the bilge-strakes are on, continue to work a few strakes upwards, in order to fasten and steady the heels of the second futtocks. The wales may also be got on with at the same time, and it is best to begin with the strake next under the upper one, working downwards as far as you can on that stage. If one or two of the diminishing strakes under the wales can be got round at the same time, it is so much the better. The height, sheer, and breadth of the bends, being set off, in the first place pick out some of the fairest going plank, as it is necessary to put them round with as little setting the edge way as possible. A rule staff should be applied to obtain the snying of the foremost planks of the wales; and in applying it, take particular notice that it is kept quite close and flat to the timbers, otherwise you will not be able to obtain the true curve of the snying of the plank.

In putting round the wales, it was formerly the practice to work the bow pieces out of the solid, from compass-timber, to the proper round and twist of the bow from the harpin-moulds; but it is now considered better to work two thicknesses of plank in those places where the curve is too quick for turning them round at their full thickness. The same object is also effected by slitting the fore ends of the thick plank in the way of such parts as run a risk of breaking by the quickness of the turn of the bow or quarters. Putting the wales round the bow in two thicknesses is considered to be stronger than by working them out of compass-timber, as you not only obtain superior lengths and shiftings, but also the growth and fibre of the plank runs more longitudinally from end to end; whereas the fibre will be more or less grain-cut when working the curve out of the compass-timber; for in this case the plank used must be very clean, and run well with the snying of the bow, so as to require as little setting the edge way as possible, particularly for the first and second strakes, as the timbers at that time are not properly fast for supporting any particular strains or settings. In working English oak plank, which is often unfair the side way, the timbers should be shored from the inside opposite to any particular inward bight of the plank, in order to preserve the fair curve of the ship's side.

Before bringing the first strake of the wales to the timbers, the plank should be well heated in the stove or boiler, and every thing in perfect readiness, so that they may be set right to their proper place before they get cool; for here (as the blacksmith says) you must strike while the iron is hot.

When the plank is brought to the ship's side, set it fair the edge way to the exact sheer-line, and fasten it to every timber. In this manner proceed with the other planks of the strake, until it is completed from the stem to the stern. In working the wales round the buttocks, it is now common to turn the after-pieces of the lower strakes up as high as the tuck-rail; in which case the lower ones are turned up as high as to be on a level with the upper edge of the upper strakes of the wales at the quarter-timber. This is a little difficult to execute, on account of the twist, which is equal to one quarter of the circle.

Supposing you have four strakes of wales, and that next the upper one to be first

run; then, although there may be very little round on its after end, there will be a very considerable twist. But it is seldom that the two upper strakes can be turned up in this manner; indeed, if the buttock is very sudden, it would be preferable to work a piece compass-timber to the twist and bevellings for the hood of the third strake down, keeping it of a good breadth at the after end, and as far out towards the inside of the upper strakes as the piece will work, in order to make the piece which will be required to fill up the corner as small as possible. The after end of the lower strake may be worked up and bent round to the twist, being a piece of good clean plank, as it will only require to be slit up with the saw from about 4 or 6 feet from the end, which must be left unslit for about 12 or 18 inches. The saw should be entered in from off at nothing, and the outside half left the thickest.

When the second upper strake is worked round, you may get on with the next under it, and so on. Continue to work downwards, and you will have the opportunity of making the wales perfectly fair in the lower edge, by keeping the upper strakes to such breadths as may be required for that purpose. In planking downwards, you are not so ready to draw or raise the different timbers from their butts.

If the stage is convenient, work round one or two strakes under the wales, and then set the bend-shores before shifting your stages. When the stage is raised, begin with the upper strakes of the bends or wales, and work upwards, taking care to make neat seams, and to keep them to the proper sheer; be particular also, to have them quite close inside, and about 1-16th part of an inch wide in the mouth for every inch the plank is thick.

In working round the bow, if it is of a raking form, or flange much out on the luff, you will require to keep the plank one-half or three-fourths of an inch broader than determined by striking the line on the timbers; for as the bow inclines outwards, you not only lose perpendicular height, but also, as the outer edge of the plank cants downwards in proportion to its thickness, if this is not attended to, the seam will look unfair. When the upper black-strakes are put round, and as these planks will stand vertical, it will be advisable to make their upper edges quite fair to the proper sheer. by placing the battens round, and running a little off here and there until they are quite fair; also try the sheer by means of the cord-line, as before directed, for sheering the lower side of the wales.

When the black-strakes are perfectly fair, all the work upwards may be easily kept so, by lining all the planks to the same breadths throughout, so that their seams shall run exactly parallel. But as the fairing round the luff of the bow is very difficult, the planks at that place must be left a little broader, and after they are on, striped off so as to be fair to the eye. The planks towards the stern must not be broader than towards the middle, but rather diminished a little, which has a very agreeable effect.

Although the above may be considered sufficient for the general rules for planking and sheering the upper works of the vessel, yet as any defect in this particular is so easily discovered when the vessel is built, even by those who could neither detect nor correct it at first when the work was going on, and as I consider it a nice point to plank a ship properly, I shall offer some farther observations on the subject.

It is the general method to work the planks of the bends and top-sides of equal breadth throughout (except when English plank is used), and of course the seams run all parallel to each other; but from the properties of the circle, every strake produces an additional sheer. Now, supposing the upper edge of the bends to be worked to the sheer of the top-sides, and proceeding in this manner with all the plank above that, by the time you come to the top or paint-strake, it will have much more sheer than what you intended. The paint-strake having more sheer than the bends, must look very disagreeable to a chaste observer. Therefore, to avoid this, every strake above the wales should be diminished in breadth towards the bow and stern. The exact quantity to diminish each strake may be easily found, it being exactly the difference between the breadth measured square off the curve towards the extremities, and a vertical measurement at the same place. Perhaps it will be necessary to explain this a little more fully by reference to a figure, for which purpose see *Plate* X. *Fig*. 27. Suppose A B C to be the upper edge of the black strake, and B D, No. 1, its breadth; D G and G H that of strakes 2 and 3. Now it is evident, that by continuing these strakes parallel, making A E and C F equal to B D, E H and F I equal to D G, H L and I M equal to G K, they will each acquire more and more sheer, the circle L K M being much quicker than A B C.

But to preserve the same sheer in the upper strakes, they must be diminished in breadth towards the fore and after ends, equal to the difference produced by measuring them square, and upon a vertical line. Consequently, in place of setting the breadth B D square off the plank, as A E and C F, set it up vertically as A *e* and C *f*; then the dotted line *e* D *f* will have the same sheer as A B C. In like manner are all the other strakes diminished. The dotted line *l* K *m* N shews the same sheer as A B C, and may be drawn with the same radius. The three strakes are thus diminished equal to the difference between the square and vertical measurements, *i. e.* the distance *m* M. Therefore, having found this distance according to any number of strakes of plank, and the distance forward and aft from the middle of the ship, you have only to divide it into the number, and diminish each strake accordingly. But this will amount to very little upon a straight-sheered vessel, although it must appear quite evident upon common-sheered ships, and for all such it should be particularly attended to.

Of late, several vessels have been built within my observation, and sheered in a particular manner. In place of being sheered to the segment of a true circle, the curvature of their upper works was gradually decreased from the middle towards the stern, leaving the circle, and approaching to that of a parabola. This curve may be set off on the sheer-draft after the geometrical method, and in the moulding-loft by calculation; but upon the vessel, it may be effected by stretching equal lengths of a straight line, observing to make the sheer diminish gradually as you approach the stern. This method, however, runs the vessel rather low abaft, and ought not to be adopted in small sloops and packets. It should also be noticed, that the seams are equally wide and regular; for should one or two of the seams happen to have too much standing-bevel about the same part of the ship's quarters, the sheer of the upper edge of these strakes will be raised more or less, and will therefore require to be lined down, and run fair to the proper sheer.

Treenailing.—As to the treenailing of the bottom and top-sides, it is the general custom to double-bore each timber on the breadth of a strake if it exceed 10 inches, and to double and single-bore all narrow strakes; that is, to double-bore one timber, and single-bore the next alternately. The size of the auger for the bottom plank, for vessels from 100 to 300 tons measurement, is inch and quarter, and for the top-sides inch and eighth. For vessels of 400 or 500 tons, the bottom is inch and three-eighth, and the top-sides inch and quarter.

Sheer-planks, in many places called the *Paint-strakes,* are the uppermost strakes on flush ships. They are commonly one inch thicker than the other plank of the top-sides, and should be worked from plank of a durable quality, and perfectly free from shakes or sapwood, as the bolts are the principal binding of the upper-deck beams, and pass through the paint-strakes. For vessels of 160 or 200 tons, the paint-strakes require to be about 11 inches broad, and 3 inches thick, and their butts hook-scarphed the edge way; also the scarphs bolted through, the edge way, with two or three bolts placed in the way of the openings between the timbers. In all vessels, the paint-strakes are commonly worked as broad as can be got, that they may have a good hold of the timbers, and allow room for the bolts of the knees of the deck-beams. Vessels of 260 tons and upwards should have two strakes, the upper one bolted down to the other, having a bolt through edge-ways, opposite the space between every other timber. The paint-strakes should be fair-going stuff, as it is difficult to get them set the edge way, and as they are not to be full treenailed until the beams and knees are bolted through them, when they are examined, and where any fastening is awanting in the feet of any of the stanchions or timber-heads, it is put in. The paint-strake should be very neatly taken to the sheer, and the upper edge dressed with a declivity outwards of one inch to a foot.

We may now suppose the ship all fast round the bilges, the shores all set, and the wales and upper-works all planked.

Planking the Bottom.—The flat of the bottom from the garboard-strakes to the bilge-plank, and the part of the bottom from the bends downwards, may either be planked or left open for the present, as may be considered most convenient. When the timber is green, and requires seasoning, it is most proper not to cover in the bottom too soon, but to carry on some other part of the work in the meantime, as to get in the deck-beams or the like. But at all events, supposing the timber to be quite seasoned, two strakes in the flat of the bottom, and one above the bilge-strakes, should be left out, in order to keep the ship clear of spales and borings until the inside work is finished.

There are various opinions respecting the method of planking the bottom, some preferring to work from the bilge upwards—others to begin at the wales, and work downwards; those of the latter opinion supposing that they work themselves sooner out of the snying of the plank by having the round edge of the plank to work upwards. But this is only supposition, for the plank must be of the same form, and have the same snying, whether you work upwards or downwards. It is no doubt true, that by making inferior work, a little will be gained by working downwards, as by having no seam to confine the planks below, they may be kept a little fuller on the luff of the bow,

and whatever they want of being set close to the seam above will be in favour of lessening the snying of the next plank under; at the same time, it is by no means an equivalent for the difference in the quality of the work.

In working upwards, when the plank is hooded, and when you are bending it round to the timbers, its own weight will assist greatly in bringing it down to the seam; then, by keeping it close to the timbers, at the same time that you are setting it down to the seam, the upper edge of the plank below will prevent it from leaving the timbers at the lower edge; whereas, in working downwards (where you have to set the middle of the plank upwards), the lower edge of the plank is free, and from having a tendency to fly from the timbers, which is increased by the action of the wedges employed to set the plank up to the seam, it is more laborious to make good work. In my opinion, planking upwards is preferable, for it is certainly easier to set the after end of a bow-hooding down, than to set its middle upwards. It is, however, very common, when the wales are put on, to work two or three strakes downwards (and it is not the least objectionable, if proper attention is paid to make good work), than to work upwards from the bilge until you close in. Supposing you begin at the wales to work on the diminishing strakes, which should all run round the bow to the stem if possible, line their breadths on the timbers; supposing them amidships to be 10 inches, they should not exceed 4 inches at the hoods. Let two or three of the strakes immediately under the thick strakes carry their breadths well forward, in order to take off as much of the snying as possible. For if the ship has a full harpin and a fine entrance below, all the planks in the bow will have a very considerable round upwards in the middle, although they appear to have it the opposite way when the ship is in the water. When not provided with proper planks to work the bow-hoodings from, it will be nearly impossible to bring them all to the stem; and if it be attempted, so much setting the edge way will be required, that several of the planks may be sprung; it will also be with difficulty that you will be able to work or keep them close to the timbers at the lower edge. Therefore it is much better to work one or two of the upper strakes short of the hoods, making what is called a stealer, allowing the strake under the thick-strakes to butt 4 or 5 feet short of the hoods, which will bring down the luff of the bow and straighten the edges of the planks under, so that they will be easier worked to the timbers. This method is allowed to make better work, but not to look well on vessels that are not to be copper-bottomed. When it is intended to run all the strakes forward to the hoods, continue to place the butts in the bow, so as to divide the snying as much as possible, which may be so contrived as to assist the working of the plank, without being injurious to the vessel by destroying the shiftings of the planks.

Having worked a few strakes round under the wales, begin at the bilge and work upwards, until you close in, only leaving out the strake next the bilge-strake, to allow the chips to fail through during the time of dressing and working the inside work.

Working the Beams.—The first thing to be done in preparing the deck-framing, is to select suitable pieces of timber for the beams. Their lengths and number are easily obtained by consulting the deck plan; and their dimensions, according to the size of the vessel, may be found by consulting the rules for the general dimensions and proportions, (*see* p. 157), also the Tables of Dimensions.

The first thing to be done is to construct the beam-mould, which should be the segment of a circle, having a curve of about 3-8ths of an inch for every foot of the length of the longest beam. However, for large vessels, where the beams are supported by pillars, if the main-deck beams have a round of one inch for every three feet of their length, it will be sufficient. The hold-beams should have only about one-half the round of the upper-deck beams, or so that the round on the upper side of the hold-beams does not exceed that on the under side of the upper-deck beams.

The timber for the beams should be converted some time before you are ready for putting them into the vessel. At first they should be sided to the proper dimension, but moulded a little deeper. They should lie in this state until they are so far seasoned as not to warp or cast; it being frequently observed that in cutting out beams they often alter their shape, some turning straight, and others acquiring more round, twisting according as the natural run of the fibres is more or less crossed by sawing the beams to the proper round and dimensions. This alteration sometimes takes place during the time of sawing them, or before they are long off the saw-pit; therefore in order that they may be of the proper curve and dimension when put into the vessel, they should not be sawn to the exact size at first, but left a little larger the deep way, that when they are measured off, and cut to their proper length, the mould may be again applied, and the beams trimmed exactly to their proper round and size, and their upper and lower sides put exactly out of winding. By taking these precautions, you will make the fairest deck with the least trouble. The carlings and ledgings should also be sawn out at the same time.

The method of pricking off the circle for the beam-mould has been described in the introductory part of this work,—*(see Practical Geometry*, p. 14.)

The beams are generally of one piece, without any scarphings or fillings, except for very large vessels of 600 or 700 tons, and steam-boats, whose principal paddle-beams are sometimes made of two pieces, it being difficult to procure timber large enough to make them all of one piece, in which case they must be properly scarphed and bolted. The scarphs should be of a good length, either cogged, as represented by *Fig.* 30, *Plate* X. or dowalled, as represented by *Fig.* 31, *same Plate.* The bolts must be drove from both sides, and well clinched on large rings, which, when well executed, is preferable to screw bolts. At the time of converting the beams, the knees and stanchions should also be brought forward; and during all these preparations, the clamps and a few strakes of ceiling-plank under them must be wrought round the inside of the ship.

Working the Clamps.—The clamps are long thick planks, running from stem to stern, to bind the vessel in the longitudinal direction, and to rest the ends of the beams upon. In addition to the clamps, some vessels have a stringer or shelf-piece bolted edge-ways to the clamp, to give a better security to the bindings. For vessels of 200 tons, the clamps are commonly of four-inch plank, as broad as the plank will work. In place of having square butts, the clamps should be scarphed edge-ways with a hook-scarph, 3 feet long, fastened with three bolts edge-ways, and to every timber with a small bolt all the way from stem to stern. For vessels of 400 or 500 tons, there should be two strakes of clamps for the beams of each deck fastened together edge-ways, with a bolt opposite to

the space between every timber. For determining the place of the upper edge of the clamps, you must consult the given depth of the hold, and the height of the 'twixt-decks, likewise the depth and round of the beams, which may be all exhibited by the plan of the midship-section. But in practice, add together the above given dimensions *i. e.* the depth of the hold, the thickness of the hold-beams in the middle, the height in the 'twixt-deck between beam and beam, and the depth of the upper-deck beams; and setting the height up from the floors at the side of the keelson, stretch a line across the vessel, making it perfectly level; then by measuring the round of the beam, down from this line at each side, and next the thickness of the beam-ends, you will have the place of the upper edge of the clamps at midships.

Having the level-line stretched across at the height of the crown of the midship-beam, set the same height up from the keel at the distance of 15 or 20 feet before and abaft midships; put lines across at these places, out of winding with that at midships, and then by looking any number of spots on the timbers, straight with these level lines, you may easily obtain a straight line fore and aft the vessel on each side, from which the sheer of the deck may be set off, and made regularly fair with the sheering battens.

Having in this manner marked the height of the upper edge of the clamps all round on the inside of the timbers, the clamps are then to be heated in the stove, and put round the vessel. After the clamps are round, the stringers or shelf-pieces may next be proceeded with, hook-scarphed and bolted to the upper edge of the clamp.

'Twixt-Deck Beams.—When the clamps and shelf-pieces are round, and every thing ready for placing the beams, mark off the station of the masts in relation to the midship-frame, also the station of all the beams, measuring them exactly from some determinate frame on the deck-plan, and setting their distances from the same frame on the ship; then set off the height of the deck breast-hook, by stretching two lines across, at the height of the crown of the two foremost beams, and running a line over the top of these, in a fore-and-aft direction, you will have the height of the deck breast-hook on the inside of the stem or apron. But before the hook is hoisted up, it must be worked to the round of the beams.

Before hoisting the beams on board, work a few strakes of ceiling-plank under the clamps, as it will be more convenient to do so now, than after the beams are in; having the station of all the beams marked off on the clamp on one side, mark them on a long batten, and transfer them to the other; but in doing so, be particular in horning or squaring them from the middle-line of the stem or keelson, so that they shall be perfectly square across the ship. In fitting the beams into their proper places, observe to place the root-end of one and the top-end of the next alternately to the same side of the ship.

The methods of taking the length of the beams, and the bevel of their ends to fall against the timbers, are uncommonly simple, and not only known by every good workman, but also may be performed by any person able to handle the tools.

When the 'twixt-deck beams are all in, kneed and bolted, you may next prepare for running the clamps of the upper-deck beams. Having dressed the timbers all fair and to their proper thickness, proceed to chock the timbers in the way of the channels and chain work. This is often done by driving in pieces between the regular timbers, filling

up all the spaces for four or five feet below the clamps. But the effect of this close chocking in the way of the chains frequently produces dry rot, and a rapid decay of the top-timbers; to obviate which, I would propose to side the top-timbers in the way of the channels greater than elsewhere, keeping them considerably broader; and to prevent them from splitting, drive in pieces of hard dry oak the endlong way between the timbers, keeping these pieces a little narrower than the deepness or moulding dimension of the top-timbers, at the place where they are driven in, so as to leave an opening between them and the outside and inside plank, in order to allow the air a free circulation. These short pieces may be drove much tighter than long pieces put the up-and-down way; they will also not slacken so much by the clinging of the timbers, for although the timbers should cling, they will not cling themselves the endlong way; in the other case, the pieces cling themselves, and the timbers clinging, they naturally become slack, and are then of no use whatever.

The stanchions should also be fitted in between the timbers, and set to the tumble-home of the top-sides the one way, and perpendicular to the keel the fore-and-aft way. The tumble-home of the stanchions for common merchant vessels is about two and a half inches to the foot of height. In every case they should have such a tumble-home that the shrouds shall not bear against the main-rail.

Clamps for the Upper-Deck Beams.—In setting off the height of the clamps for the upper or main deck, when the vessel is to be flush fore-and-aft, you may proceed after this manner:—Prepare a number of pieces of wood 12 or 18 inches long, about half an inch thick, and two inches broad; make them straight and parallel in the edges; place one across the gunwale at midships, resting it on the edge of the paint-strake, and it will lie with a declivity outwards of one inch to the foot of its length, as the upper edge of the paint-strake (as before directed) is dressed to that angle, in order that the covering boards or plank-sheer may lie with the proper declivity. Having fastened the batten at the proper declivity outwards at midships, put several others across at different places of the side before and aft, and look them all out of winding with each other from the fore-frame to the quarter-timber (the more of these winding battens you employ the better.) In going round the bow, be particular in winding them at very short distances. Now, if the upper edge of the paint-strake has been sheered, the under side of these winding battens will mark the under side of the covering board on the inside of the timbers. But if the paint-strake has not been taken to the exact sheer, you must prick the height that the lower edge of the batten is from the same, and set it down from the batten on the inside of the timbers. Take the sheering batten, and plying it round at all these spots, so as to make a fair sheer, draw it by; then from this line set down the deepness of the water-ways and spirketing where intended, and you will then have the height of the upper side of the ends of the beams marked on the inside of the timbers; but this will only serve to run the beams as far as the deck runs parallel with the sheer of the gunwale or covering-board. Therefore, from that to the stem, the deck must be straightened, and run to a height to suit the hawse-holes, which will also determine the quantity of spirketing or quick-work. Next put a few pieces of straight ribbands across at the height and place of a few of the foremost beams where it is intended the deck shall have the regular sheer

of the gunwale; then laying a batten fore-and-aft on these cross-battens, and bringing the fore-and-aft batten fair, it will mark the height of the deck on the inside of the apron. By stretching level lines across, touching the under side of the fore-and-aft batten, then measuring down from these lines, at each side, the round of the beam, according to its length, you will have the upper side of the ends of the beams, and consequently, measuring down their thickness will give the height of the upper edge of the clamps.

If the ship is to have a deep waist, to suit some particular service or trade, it will be necessary to have the deck-lines drawn on the plan and laid down on the floor of the mould-loft, and marked on the frame-timber moulds, or their exact height in feet measured and set down in a note-book, or properly delineated on a plan of the inboard work.

Fitting and Binding the Beams.—When the clamps are all round, and the shelf-pieces properly fastened, the beams are next to be put in; and when laid to their proper stations, make them perfectly fair on the top in the fore-and-aft direction, by letting some of them down a little into the shelf and clamps, and fasten them down with two bolts and a dowal.

There are many ways of fastening the beams to the ship's side, as by wooden fore-and-aft knees and iron hanging-knees. Others have no fore-and-aft knees, but have the beams fastened by dovetailing them into the shelf and clamps, letting them down one-third of their thickness; and then on the upper part are fastened the two legs of a strong plate of iron, which passes round the timber opposite the end of the beam. When the beams are thus dovetailed so far down into the clamp and shelf-piece, these must be placed so much higher; for that purpose, also, the shelf-pieces must be a little thicker in proportion.

Of the several methods of binding which I have seen practised, perhaps the following (represented by *Figs.* 28 and 29, *Plate* X.) is the most complete, as it combines strength and firmness, lightness and economy; it also takes up very little room, and allows a free circulation of air round the ends of the beams. The lower figure is the plan of a part of the side, and the upper figure a section of the same—the same letter refers to the same parts in both; A A is the outside plank or paint-strake, B B the top-timbers, C C the clamps, D D the strake of ceiling, and E E the beams.

Now in this case the beams are merely rested on the clamp and a piece of 4½ or 5-inch plank; F is dovetailed on the upper part of the beams, as shewn by the figure, and bolted firmly to every timber, having also two bolts through the end of each piece into the beam. In binding after this manner, begin forward or aft, and having fitted in the piece between the two aftermost or foremost beams, set them hard together; then fit in the piece between the next beam again, and so on, continuing to work from one end of the ship, always setting the beams hard against the pieces, and bolting them as you go on. When to this fastening are added iron-knees, the vessel will work less than with any of the other clumsy methods of binding which are commonly used.

Deck-Framing.—When the beams are all fitted, and properly fastened, the position of the hatches, chocks, &c. must be marked off, and the coamings, partners for the

masts, ledges, and carlings proceeded with. In the first place, a centre-line of the ship from stem to stern must be marked on the beams, by stretching a line from the centre-line of the stem to that of the stern-post. This line must be raised or scratched across the top, and down the sides of all the beams, to prevent it from wearing out.

Beginning forward, and proceeding aftwards, first fit in the chock for resting the heel of the bowsprit upon, which must be a piece of good solid timber, about the size of the beams between which it is fitted, let into each about 3-4ths of an inch, and properly secured. Next fit and bolt the topsail-sheet bitts, the partners for the fore-mast in brigs and ships, and the pawl-bitts and windlass-bitts in smacks and schooners. These bitts may be fixed in different ways. Some builders fit down a piece of four or five-inch plank between the beams, chacking it one inch into each beam; then covering this with an oak plank of the deck, through both of which the bitt is let down, and also through another piece of four or five-inch plank, which is bolted on to the under side of the beams, and a bolt is then put through the edge of this under piece and the lower end of the bitt. But the common method is more compact, and equally strong; *i. e.* to fit a strong piece of timber between the beams about the same thickness as the beams between which it is to be fitted; and having its breadth equal to $2\frac{1}{2}$ times the thickness of the bitts which are to pass down through it, natch it one inch into the beams at the upper side, lessening gradually to about 3-4ths of an inch, to within 2 inches of the lower side of the beam where the natch ends, leaving a rest for bearing up the chock. The chock must be neatly fitted, and made as tight the side way as possible.

The width of these chocks from the centre-line must be regulated according to the intended length of the windlass, and this between the bitts is commonly about half the breadth of the deck between the gunwales at midships. When the chocks for the windlass-bitts are fitted, a mortise is cut down through them, to receive the end of the bitts, which are driven tight down, and bolted thwartships through the chock, which must be firmly bolted to the beams.

The Chock for fixing the Capstan-Spindle should also be done in a similar manner. As this piece is exposed to oblique and canting strains, it should be secured with a small knee on each side, bolted firmly to the beam at the end of the chock nearest to the place of the spindle. It should also have a strong ledge on each side. The partners for the masts of square-rigged vessels are commonly pieces of oak plank 4 or 5 inches thick, and 10 or 12 inches in breadth; but for large one-masted vessels, such as cutters, or the Leith and London smacks, which are 200 tons measurement, the partner for the mast is a piece of 8 or 9 inches thick, and 10 or 12 in breadth. They must be very neatly let in between the beams, and well secured with stout bolts. The partners are not required so thick as 8 inches merely for supporting and holding the mast in its place, as the edges of all the deck-plan on each side contribute to this purpose; but when the partners are thin, they are supposed to chafe the mast, and the wedges soon become loose, as they then have only a small surface to support them against the strains of the mast.

After the partners for the masts are fitted, you proceed aftwards and fit all the coa-

mings for the hatches, sky-lights, companion, &c. *ledges*, *carlings*, and all the principal deck-framings.

It ought to have been mentioned, that the beam at the stern-post will not require to be so thick in the middle as the others, from being chacked into the fore side of the stern-post a little, and bolted, and is thus supported by the stern-post. If the stern-post is strong from the wing-transom upwards, and the beam which crosses the deck at the same place firmly bolted to it, it will be of great service in supporting the quarters of the vessel from working.

The aftermost beam, commonly called the deck-transom, answers better to be broad and thin than deep, or to be of the dimensions of the other beams, as it will leave more room for stern-windows in small vessels. The breadth of the beam for the deck-transom may be a little more than the others, and its thickness about one-half of its breadth, it being of the same thickness throughout. It is sometimes worked out of a solid piece, and sometimes a straight piece is bent to the round-up of the beam-mould, after being properly heated in the stove. It is moulded to the round aft of the stern, and bolted to all the stern-timbers, with a knee at each end, bolted through the stern-timbers and quarter-timbers.

While proceeding with the deck-framing, the breast-hooks must all be got in and bolted; sometimes they are fitted on the ceiling, but it is better to fit them to the solid timbers.

By *framing and warping the Deck*, is meant putting in the beams, knees, coamings, &c. and dividing the space between the beams into regular distances from side to side of the vessel, perhaps into three or four spaces, by means of fitting between the beams fore-and-aft pieces of from 4 to 5 inches square, called *Carlings*; these are let one inch into the beams, and drove tight down (both the end and side way) flush with the top of the beams. The spaces between the beams are again divided the fore-and-aft way, by pieces dressed to the round of the beams, and fitted between the carlings, running parallel with the beams.* Their dimensions run from 3 to 3½ or 4 inches square; they should be made of good clean timber, well clear of knots. (*See* the Deck-plan of the ship of 400 tons, *Plate* XXIII.)

The principal use of the carlings and ledges is to give a more uniform support to the planks of the deck; they are sometimes, in ships of the Navy, placed diagonally to the beams, and a part of the deck is laid in the diagonal direction, in place of running fore-and-aft. This, however, will not answer in merchant vessels, as these are not so substantially bound by stringers and braces the fore-and-aft way as the war vessels, and therefore depend more upon the deck-plank for the longitudinal tie of their upper works. It is much doubted whether the diagonal decks confer any advantage whatever, even on war vessels. They may indeed prevent the vessel a little from working transversely, but I cannot perceive that they will have the same effect in binding her as if laid the fore-and-aft way. It is also difficult to keep them tight, on account of their having so many oblique butts.

* As the carlings and ledges obstruct the stowage of flax and other light goods, vessels for the north country trade should have their beams placed a little closer, and no carlings between them.

Water-Ways.—After the deck framing is completed, the water-ways may be next put round. These are the thick planks at the outside of the deck, which fit against the inside of the top-timbers. They are considerably thicker than other planks of the deck, and hollowed out so as carry the water which drains from the crown of the deck to the scuppers. The gutter should be so formed that the water may not lie in the seam of the water-way with the next adjoining plank of the deck.

The water-ways should be of oak, or such like durable timber, as they are much exposed to alternate states of wet and dry; also, as they are connected to the sides and ends of the beams, they are exposed to very considerable strains by the working of the ship; and as they are excluded from a free circulation of air about their lower sides, they are more ready to decay than any other of the deck planks; therefore it is absolutely necessary to select the most healthy and durable timber for the water-ways. In putting them round the vessel, they must be fayed close down on the beams, and well fitted to the inside of the timbers. Those to go round the bow must be worked to the curve from compass-timber, and fitted and bolted down to the breast-hook. The after piece should extend across the inside of the quarter-timber, and be let one inch into its fore and inner sides, so that this part may be easily made tight. The piece that goes across the stern should be of a good breadth, and natched one inch round the three sides of the stern-timbers, to strengthen the back rabbet for the inside stern-plank, leaving sufficient room before the rabbet to bolt it properly down to the beam or deck-transom, to prevent it from surging aft when caulking the butts of the deck ends. The ends of the stern-piece or water-way must be neatly mitred against the side-pieces, and done in such a manner that the mouth of the one seam may not overlap that of the other, as in that case it is very difficult to get them properly caulked. The water-way strakes should be bolted from the stem all the way round to the stern, down to both beams and knees, and also edgeways through every other top-timber.

Spirketing.—There should be a shallow rabbet cut out of the upper side of the water-way at its back edge, going fair round by the inside of the timbers, to receive the lower edge of the standing water-way or spirketing, of which there there will be more or less, according to the different sheers of the deck and gunwale; therefore the spirketing may be either one or two strakes forward, and tapering off towards the fore chains, or it may run all round the vessel, and be of any deepness, according as the deck is below the gunwale. But the plank-sheer or covering-board in merchant vessels answers the purpose of the gunwale, and fits close down upon the water-way, all the way from aft to where the sheer of the vessel leaves that of the deck, or where the deck begins to decline from the sheer of the paint-strake, which is commonly about the place of the foremast in ships and brigs. The spirketing should be hooded into the after edge of the hawse-timbers, and run off to a narrow point towards midships. It is necessary that the rabbet in the water-way, at the place where the under side of the gunwale joins the water-way, be cut a little deeper, about the breadth of a caulking iron or so, that the spirketing may not be run off to a thin point. The spirketing should be bolted edgeways down to the water-ways, the bolts passing also through the knees and beam-ends. When the water-ways and spirketing are fitted, a few strakes of the deck-plank must be laid, before

proceeding to fit the gunwale or plank-sheer. When the vessel is to be strongly bound, an oak plank, about 3-4ths of an inch thicker than the deck, is laid next to the water-way (the beams being natched to receive the additional thickness of the plank); it is bolted down to the beams, and in this case the bolts which fasten the water-way to the side pass also through the oak plank. But as natching the 3-4th inch out of the beam, to allow the oak plank to come flush with the deck, tends to weaken them, and may harbour damp, which is prejudicial to the beam, it would be better to keep the oak plank of nearly the same thickness as the other deck plank, and fasten it down with two small bolts and a dowal to each beam. Dowals are always preferable to any chacking, for this cannot be fitted so exactly but what there will be some parts open, whereas the circular coag or dowal may be made to fit very exactly. After this oak plank is fitted and bolted, and a strake or two of the deck laid within it on each side of the deck, a few hands may begin to saw off the tops of the timbers, and fair away for the plank-sheer or covering-board, dressing the top of the timbers fair across from the edge of the paint-strake to the top of the water-way and spirketing.

Plank-Sheer or Covering-Board.—The plank-sheer lies upon the upper edge of the sheer-plank or paint-strake, the heads of the timbers and upper side of the water-way, and edge of the spirkteing, to which it must be closely fitted and bolted down. It must fit close round the timber-heads, stanchions, &c. so as to be water-tight when caulked. In the north of England, and most parts of Scotland, the plank-sheer is very properly called the covering-board.

The plank to be used for the covering-boards should be very fair-going material, quite free from shakes, otherwise it will be difficult to get them let down over the stanchions and timber-heads; they will likewise be easily split, and very difficult to be kept water-tight. Before the covering-boards can be put on, the timber-heads and stanchions must be dressed fair, and tapered a little, so that the covering-board will pass over them, and fit tightly all round them, when it is close down to the water-way and paint-strake. Also, before the covering-boards are put on, the scuppers for running the water off the deck must be marked; these must not pass through any of the top-timbers, but between them. But it is found not to answer, unless they pass through the solid; therefore a piece of timber must be fitted in the space through which thes cuppers or scupper is to pass.

Being thus prepared for letting down the covering-boards, proceed to take a spilling for them. First take a piece of thin wood as broad as the covering-board is thick, and laying it across the timbers against the fore and after side of the stanchions, scrive them by its upper edge, and it will mark the exact thickness of the covering-board on the sides of the timber-heads and stanchions.

Next take a broad piece of fir deal for a mould or rule-staff, and lay it along the outsides of the timbers at the height and declivity of the upper edge of the covering-board (which is determined by the scrive on the sides of the timber-heads and stanchions) with the compasses; take all the marks for the mortises to be cut through the covering-board, that it may pass down over the stanchions and timber-heads.

When the covering-boards are fitted down, they must be fastened with small bolts to the edge of the paint-strake and water-way.

The covering-boards are sometimes fastened down with nails a little larger than those used for the deck; but it is found to answer better to use small bolts, about half an inch thick, and nearly three times the thickness of the covering-board in length, drove in about 14 or 16 inches apart; also there is commonly a 5-8th inch bolt drove through the edge of the covering-board and through the stanchions and timber-heads. This bolt is clinched on the inner edge of the covering-board, which secures it from splitting by the caulking of the stanchions, or from being raised up by caulking the side seams, *i. e.* the seam formed by the lower side of the covering-board and the upper edge of the paint-strake and water-way.

After the covering-boards are put on, the deck may next be laid, or the ceiling-plank wrought on, as may be most convenient. Before laying the deck, all the coamings for the hatches must be bolted to the beams; the pawl-bitt, topsail sheet-bitts, &c. all fixed; also lay down an oak plank on each side of the coamings, 3-4ths of an inch thicker than the common deck-planks, for fixing ring-bolts, &c.; and the oak plank for fixing the windlass-bitts and capstan should be also fitted and bolted down to the beams.

The best timber for decks is Dantzic or Memel fir, or the American red pine makes a very fine fair deck; also the yellow pine makes a very fine deck for steam-boats and vessels exposed to a hot climate.

Laying the Decks.—The dimensions for the decks, according to the size of the ship, run from 2 or 2½ inches for vessels of about 60 or 80 tons, to 3 or 3½ for ships of 400 or 500 tons; and the breadth of the strakes varies from 6 to 8 or 10 inches. They should never exceed 10 inches in breadth, otherwise they will cling so much that it will be difficult to keep them tight.

In laying down the deck, care must be taken to place the heart-sides of the plank undermost, particularly those which are cut from the middle of the tree, as they are very apt to scalve or rise up in flakes by the heat of the sun, and thus produce shakes in a diagonal direction, which are much more difficult to make tight than those which go square through the plank. These oblique shakes, although they may be made tight at first, seldom continue long so, as they frequently open and rise up so as to take in wet and dust, which soon rots the plank, and is also prejudicial to the beams. Care should also be taken to make the lower edges of the seams very close, and to set the planks hard upon each other, all which may easily be attended to with little or no additional lose of time. Indeed, by paying attention to these and similar particulars, the work will not only be better, but even facilitated in proportion as there will be less chance of mistake, and a second doing over again but rarely required.

The seams of the deck should all run quite fair fore-and-aft, and their upper edges be kept about 1-16th or 1-8th part of an inch wide. The edges of the plank should be all stripped fair and square with a plane, and the round of the beams will throw the upper edge of the seam a little open.

The butts of the deck-plank should be judiciously shifted, having nowhere less than three strakes between, and 4 or 8 feet of shiftings, according to the width between the beams. If the planks exceed 6 inches in breadth, they should be double-nailed on each beam, and have one nail in the ledges or carlings.

In fitting the carlings for the diagonal decks, they are placed obliquely between the

beams, raking outwards and forwards towards the bow; and the planks cross the carlings at right angles, raking aftwards towards the stern. Their outer ends are received in the rabbet cut in the water-ways; the inner ends butt against thick strakes running fore and aft at the side of the hatches. The planks of the diagonal decks cross the beams at an angle of about 35 or 40 degrees.

Improved method of laying the Decks.—The deck is a very important part of the construction, not only as it is the covering which prevents the water from entering the vessel, and thereby preserves the cargo and secures her from being filled by the waves breaking over the sides, but also in forming a platform to carry the people in working the ship, to place the guns on in time of war, and to erect the different cabins upon. The deck also forms the principal tie which preserves the form of the vessel in the longitudinal direction, and prevents her from falling down towards the two ends, which are not sufficiently borne up by the vertical pressure of the water, answering the same purpose in respect to the longitudinal, that the beams do in binding the vessel in the transverse direction.

The decks are an expensive part of the hull of a vessel, and it is therefore desirable that they should be as efficient and durable as possible. Vessels commonly wear out their decks before they fail in other parts.

The defects to which decks laid in the common manner are subject, are, first, they are commonly laid down of a very considerable breadth, from 9, 10, to 11 inches; but it is found, that at this breadth the shrinking and clinging, by the seasoning of the timber, opens the seams to such an extent that they cannot be properly caulked, and consequently the deck very soon becomes leaky, and not sufficient to preserve the cargo from being damaged. The remedy for this defect is to middle-seam each plank, that is, to cut it along the middle, and down so far the thickness-way, and then run a thread of oakum along the seam, and caulk it nearly as any of the original seams of the deck. This, if carelessly done, has a bad effect, but if well executed, a very good effect, as it not only condenses the plank, and forces the original seams close together, but also prevents the planks from throwing or casting by the heat of the sun; it has also an effect in preserving them from shelving. But although it removes these defects, it does not remove others to which they are also subject. When planks of 10 or 11 inches in breadth are cut from the logs of timber recommended for decks, their breadth bears too large a proportion to the diameter of the log or tree itself; wherefore the planks are generally deficient, having shakes or blue wood on the edges, and are also knotty, these being inseparable from broad deck-plank. If a real good deck is desired, the plank is reduced to 7½ or 8 inches, which causes considerable loss of material, and of course becomes expensive. But with a view of saving this expense of waste of timber, the logs are sometimes cut into quarters, and the planks made about six inches in breadth. These narrow strakes make a beautiful deck in appearance, but are equally objectionable, as they are not free from shakes on one edge, and being too narrow for double nailing, and too broad for single nailing, they are not sufficiently fastened down to the beams; not only this, but as they are so narrow and unsupported by one another, if any weighty thing should fall upon a single plank, it will be the more easily started than if it were a broader plank under the same

circumstance; therefore it is pretty generally considered, that plank of about eight inches in breadth is the most suitable for merchant-vessels, although they are a little more expensive than if they were either broader or narrower. But as this expense is considerable, and as some other methods may be adopted, which would answer all the purposes required, at a moderate expense, I shall propose the following, which I think cannot fail in making the best deck.

The best material for decks, in respect to strength and durability, is the Dantzic or Memel fir, but these are commonly very full of rough knots, and these knots being harder than the other parts of the wood, project up when the deck is worn a little, and make a very disagreeable surface to walk upon.

The American yellow pine makes an excellent deck; it stands the heat well, and is almost completely free from knots; it therefore wears equally, and always presents a smooth surface.

The method of fastening the deck down to the beams, was frequently complained of —this was done with iron nails or spikes; but the recess made by punching the heads of the nails down into the plank, lodged water about the nail which soon corroded it, and rotted the deck around it, and therefore the deck leaked at the nail holes; but sometimes the hole above the head of the nail is filled up by putty, or a small piece of wood, in the form of a diamond, is sunk into the deck above the nail heads, to answer the same purpose.

The deck-nails are now generally made of a composition of copper and tin. I have seen a ship's decks all fastened down to the beams with wooden pins, or small treenails, which make an excellent fastening; but as the end-wood does not wear so fast as the side-wood, these pins stand up when the plank gets wore, and of course they require to be dressed down. I have no doubt that this way of fastening is superior to the common method by nails, all things considered.

After these preliminary remarks, I shall proceed to give directions for laying the decks on an improved principle. In place of cutting the timber for the deck into planks of the common breadths, I would propose to saw them to the proper thickness, and then into pieces of 3 or 3½ inches in breadth. Construct an exact plan of the deck on a pretty large scale (say half an inch to a foot or so), by measuring the length of the ship, and the breadth between the water-ways over the round of the beams; and thus having the length, breadth, and boundaries of the deck, divide it into a regular number of strakes, each equal to three breadths of the plank at the broadest part, and diminishing them fore and aft, according as the vessel rounds-in towards the bow and stern; then divide each of these into three narrow strakes. But it is not intended to lay these narrow strakes singly, but to join them together, so as to form planks of 9 or 10 inches in breadth, and then to lay these built planks, as represented by *Fig.* 32, *Plate* X., where A A A is the top-timbers of the side,—B B B the water-way, bolted to the side and down to the beams D D D, and ledges, or half beams, E E E,—C C C, C′ C′ C′, and C″ C″ C″ the built strakes of the deck, the strong black lines being the main seams, and the light-drawn intermediate lines the seams of the narrow pieces.

The plan of the deck being thus drawn out, and the butts all marked, it may be

given to the foreman joiner of the yard; and he, with three or four good hands, will soon prepare all the deck-plank, and make them ready for laying down, by planing the sides intended to be laid next the beams, and squaring both edges of the pieces from the same, making them fair and to the proper breadths, to form regular strakes or courses, marking them so that they may be put together and laid down in their proper places, according to the deck-plan.

By cutting the deck into narrow pieces of 3½ inches in breadth, they will season perfectly during the time of working, and a considerable advantage will result from it being in the power of the workman to turn any edge of the pieces up, so that the layers may stand up and down when the deck is laid, in which position it will wear twice as long as when the circular layers of the tree are lying horizontally, which they must do more or less, when the planks are of any considerable breadth. Also by this method the best deck may be made with the least waste of materials, as a deficient or shaky plank, which could not be laid down in a whole breadth, may be rinded up, and the best parts of it taken, so as to build any of the strakes, and form a deck perfectly free from knots or defects of any kind, which may be acquired at the expense of only a little more labour, and a few iron nails to fasten the narrow pieces together. The nails may be about 5 or 5½ inches long, and 1-4th of an inch thick. In fastening the narrow pieces together three and three, place the nails so as to be in the spaces between the beams, as shewn by the figure referred to, strake C' C'. The built planks are then to be nailed down to the beams with composition nails in the common manner, two in the beams, and one in the half-beams or ledges.

If the seams of the narrow pieces are served over with a little white lead before nailing them together, they will never require caulking, as from their being cut in narrow pieces, they will season very fast, and cling but little. Nevertheless, should they cling so as to become a little leaky, they may be slightly chinsed.

Another method of laying the same kind of deck, and a farther improvement, particularly with respect to the fine appearance of the deck, is to lay each of the narrow strakes singly, fastening them edge-ways to each other as you go on laying them, and to nail them down to the beams by driving the nails through the edge of the plank, so that there would not be any nails down through the top of the deck, which may be done thus:—When you have all the narrow strakes planed to the exact breadth according to the deck-plan made out as before directed, begin and lay one strake fore and aft next the water-way, boring holes both in the edge of the water-way and plank; then put wood or iron dowals half way into the water-ways, leaving their other half projecting out, to go into the edge of the plank, as it is set to the seam. These dowals, if made of wood, may be 3½ inches long, and 5-8ths or 3-4ths of an inch thick; if of iron, the same length, and 5-16ths of an inch thick in the middle, and tapered off towards the ends. They should be placed rather nearer the lower side of the plank, and one between every beam and ledge.

It will be found that the dowals, if tight, will assist powerfully in holding the seams close together. The strake next the water-way, or at any other particular part, may be kept broader than the others. But as it will be a little difficult to dowal the planks

together, they may be nailed edge-ways with proper nails made for the purpose. The strakes being narrow, only every other seam would require caulking at first; and if, after the ship had been running for some time, the intermediate seams should be leaky, they may then be caulked.

The nails are not to be driven down through the top of the deck, but down through the edge, sloping them so as to have a good hold of the plank and the beams; and every narrow plank having a nail through its edge down into each beam and half beam, they will be better secured down than broad planks usually are. The inside edge of each plank being thus held down to the beams, the outside of the next is also held down by the dowals or cross-nails that nail each strake to its next one.

The method I have now described is fully exhibited by *Fig.* 33, *Plate* X., which is the plan or section of a part of the deck. A is the top-timbers, G the clamps, F the shelf-piece, D the beams, B the water-way, C C C C C C strakes of the deck fastened together with wooden or iron dowals, C′ C′ C′ C′ four strakes fastened together with nails, to shew both ways.

A bare inspection will now be sufficient to understand the method fully; it is therefore unnecessary to describe it any farther. It is certainly far superior to the common way of laying decks, and is strictly consistent with principle. By it the deck will not only look better, but actually last longer, be easier kept tight, and better secured down to the beams. I have seen a two-inch Memel flooring done in this manner, and I have no doubt of its answering equally well for ships' decks.

Another way of fastening the planks down to the beams (see *Plate* X. *Fig.* 34) is by putting screws (of about 4½ inches in length, and 3-8ths of an inch thick) up through the corner of the beams into the deck, a small natch being taken out of the side of the beam, so as to form a shoulder for the head of the screw; or it may also be done by nailing a strong fillet along the upper edge of the beams, and putting the screws up through it. This method will be a very great improvement on laying ships' decks; all passage vessels and pleasure yachts, particularly, should have their decks done in this manner.

Ceiling, or Inside Planks.—The deck being now laid, I shall next make a few remarks on working-to the ceiling-plank, treenailing-off, and such other particulars as are generally carried on at this stage of the work.

It is the practice in many places to leave the timbers under the beams, and such other parts as are unconnected with the clamps and bindings, all open, until such time as the deck is laid and caulked, for the purpose of keeping the work dry, and seasoning the timbers. Before commencing to put on the ceiling, the timbers must be all dressed fair, and the chocks all put on and properly fastened—observing, before they are fixed down, to drift out the treenails from the thin part of the scarph of the heels of the timbers, in order to bore up through them and the chock. All the treenail holes through the timbers must be carefully examined, to prevent the chance of any holes being left unfilled, which has sometimes happened, from the holes being bored from the inside, and perhaps not completely through the outside plank, but within a very little of it. Now, when you come to bore from the outside, to put the holes through the ceiling-

plank, if this is not observed and filled with a treenail, it may afterwards break out and cause the loss of the vessel. Knowing that this has often happened, and been attended with dangerous consequences, it is proper to remind such persons as have the charge of the building, of the importance of attending particularly to this part of the work.

The next thing to be done, after having examined that all the holes from the inside are also through the outside plank, is to clean all the chips and dirt from between the timbers. The treenails which do not come through the ceiling must be properly wedged in the timbers, observing that where there is not a sufficient number of treenails to come through the ceiling-plank, such of them as are not necessary to hold the outside plank firmly to the timbers, until you get the others driven, must be drifted out before laying the ceiling.

Being thus prepared, you may proceed to work-to the ceiling, observing to place the butts on different timbers from those on which the opposite strakes of the outside plank are butted, in order that the butts of any of the strakes of the ceiling may make shifting past those of the outside strake of plank at the same place of the vessel.

The butts of the ceiling-plank should be placed at least two or three timbers before or abaft those on which the outside plank at the same place are butted.

The ceiling-planks are commonly shorter and inferior to the outside planks; at the sametime, the inside work should be well executed.

As the ceiling-planks are commonly shorter than those on the outside, their butts naturally come nearer each other, and therefore they require to be properly considered, or they will chance to come opposite to the butts of the outside plank.

In working-to the ceiling, the plank must be properly fitted, and set hard against the timbers, and most particularly on the round of the bilge, their edges should be properly bevelled, and when more than 7 or 8 inches in breadth, the back should be rounded across a little, so as to lie solidly down upon the timbers. They should be set hard together, and well fastened down.

When one strake is laid (and it is immaterial where you begin first) you must have a few hands outside to bore up the treenail-holes, at the sametime the ceiling is held down to the timbers by spikes or small bolts; and before the plank is laid down, you must observe to mark where the spikes or bolts are to be driven, so as to keep them clear of the treenail-holes. By properly fitting and fastening the ceiling, particularly along the bilge, the futtocks will be considerably supported, being strongly bound together, and the vessel will strain less when lying on the ground. All common built vessels will strain more or less, when lying on the ground with a heavy cargo, the principal pressure in this case being on the bilge. When the ceiling is all fastened on to the timbers with spikes or bolts, the holes through the outside plank and into the timbers are bored up through the ceiling, and the vessel all treenailed-off. The boring off is frequently performed by labourers or young apprentices, and as these work under the eye of the journeyman at the same job, they will see that the former do their part in a proper manner.

Treenailing-off.—One thing which should be particularly attended to by the master or foreman at this time, is to see that all the augers for any particular part of the

vessel are exactly of the same size; for if this is not the case, it will be almost impossible, without a vast deal of trouble, for even an expert workman to drive the treenails so well as he would do with ease when the holes are all bored with augers of exactly the same size.

The treenailing-off is very frequently performed by inferior hands. The operation, though simple, being one whose effects are well known to be very important; therefore we may suppose that it is more an error of the will than the judgment to slight this part of the work. There are few builders or their foremen who are not aware of the advantage of having the plank well fastened; for my part, I would have the best workmen to execute this part. The treenails should be made from the most durable quality of timber, English oak being considered very suitable for this purpose; and real good well-seasoned Dantzic or Memel fir for a fir-bottomed vessel. The treenails should be made and drove with accuracy and attention, so as to be tight into the plank and timbers; for although the framing and bindings be the best possible, yet if the treenails are carelessly driven, or be of a bad qualiry, such a vessel will soon become loose; and as the bindings will be little assisted by those of the plank, they will also soon become loose, as they will suffer greater strains, and the ship soon become leaky and require to be re-fastened. Therefore the treenails should be made of the best materials, well seasoned in the open air, where they are exposed to all sorts of weather; which mode of seasoning produces treenails much stronger than those that are seasoned in the shade and kept quite dry. The treenails should be properly rounded, and of equal thickness from the point to within 1-4th of their length from the head, where they should begin to swell a little. By properly driving such a treenail, it will draw the plank close up to the timbers. On the bilge and other round parts of the ship, the treenails should all be wedged up to prevent the plank from starting from the timbers with the strain of caulking.

When the vessel is treenailed-off from the outside, you next saw off their heads close by the plank, and dress her quite fair from stem to stern, and also from the keel to the gunwale; then prepare to caulk.

Caulking.—The caulking (which is also a very essential part of the work) is filling all the seams with oakum, by driving it tight in between the edges of the plank, every rent and crevice where water may possibly penetrate. The caulking not only answers the purpose of making the vessel tight, but also helps to consolidate and strengthen the whole ship in a very considerable degree, as it sets the edges of the plank all firm, and to bear hard against each other, so that one part cannot move or work independent of another. The oakum employed should be good and fresh, otherwise it will soon rot in the back part of the seam, and speedily waste and consume the edges of the plank. In caulking where the seams happen to be rather close, great care should be taken not to chock them in the mouth or half-way in, which may very easily be done, by using too large threads at first. To avoid it, you must fill the seam gradually by small threads at a time, driving each properly back before you set in the next. If possible, the oakum should be driven back to the inner edge of the plank, which at some parts of the work may be very difficult to get done, particularly in the butts that happen to

be too close. In this case, the butts which are too close to be caulked properly, should be carefully widened by cutting a little out of the butt with a thin chissel or firmer.

In most of the building yards, the shipwrights also caulk the vessel. But of a number of men, there are always some who never get properly into the true and easy slight of caulking. There is a great difference among shipwrights with respect to their skill in that art, although they are all obliged to do an equal quantity of work. As a bad hand has to caulk as much as his more expert fellows, it cannot be so well done, but must be slighted or chocked in some manner or another. Indeed it is frequently observed, that some of the worst hands will have their task done before the others, without having evinced any extra application. It is therefore easy to conceive how the work is deficient in many respects, when carried on under these circumstances, and the reason why new ships are often leaky during their first voyages. Every young shipwright should be properly learned to caulk, by being placed under the charge of a good caulker, whose directions and example alone can be sufficient for this purpose. As it is of great importance to have a vessel well caulked at first, a certain number of good caulkers should be selected from among the shipwrights, or regular caulkers (persons who do nothing else) employed. At the time of dressing the ship, all the butts and seams should be regularly opened, according to the thickness of the plank. It is quite the same thing whether you begin at the keel and caulk upwards, or at the top and caulk downwards.

By *squaring-off,* is meant the tightening of the treenails, and chinsing all the rents and shakes in the plank.

With respect to the tightening of the treenails, it answers two purposes, keeping the water from running up the pores or by the sides of the treenails, and the plank from drawing or starting off from the timbers, and may be done in different ways. In many parts of the south of England, the treenails are made tight by caulking them crossways, which swells out the head of the treenail. (*See* first strake, *Fig*. 126, *Plate* VII.; those of a larger size in form of a triangle—*see* second strake; and the largest treenails in form of a square—*see* third strake.)

In the north of England, where an immense number of vessels are employed in the coal and coasting trade, their vessels are much exposed to striking the ground in going over bars in entering and leaving harbours, and in lying on the ground at times with heavy cargoes. The shipbuilder and masters of such vessels ought to know well what methods answer best to keep the treenails tight, and prevent the planks from drawing or starting over them. Accordingly, at these places, and several others, they tighten the treenails by driving three small tapering wedges or plugs into the head of each treenail. These plugs are made of well seasoned oak, and are about $1\frac{1}{2}$ inches long, and 3-8ths of an inch square at the head, and drawn to a sharp point; they are called punches.

That these should hold firmer than one large plug, is evident and consistent with theory, on account of their having a greater surface for the friction to act upon in proportion to their actual united contents, than one single plug which would swell the head of the treenail to the same degree. However, I have heard the following objec-

tion to this method of securing and tightening the heads of the treenails, viz. that in hot countries the punches in the treenails in the upper works of the vessel, when much exposed to the heat of the sun, are frequently observed to start out, and therefore not preferable to caulking the treenail-heads, as before mentioned.

The most general method used in Scotland is to drive one large plug or punch into the centre of each treenail, these being made of dry oak, about 2½ inches long, and 5-8ths or 3-4ths of an inch square at the head. If the treenails are made of fir, the plugs are often of fir also; but either oak or fir plugs may be used for treenails. I have never heard any objections made to this last method of plugging.

When the treenails are all plugged, and the rents all caulked, the seams must be paid over very carefully; and one day's work of the caulking being thus finished, the same process is gone through the next day, and so on until the vessel be all completely caulked.

N.B.—The seams in the way of such parts of the ship as are to be painted, are commonly paid over with rosin, which is cleaner than pitch; but the pitch is preferable on all other accounts, as it is found that the rosin rots the oakum, and very soon decays itself.

If the outside plank is to be planed, it should be done immediately after the bottom is dressed; and after the ship is caulked, the seam edges and treenail heads will again require a touch over with the planes, to take off any part of the seam edges, treenail heads, &c. which may have started a little by the strain of caulking.

Windlass.—The ship being now supposed all bound, decks laid, ceiling on, and all caulked, we have next to take notice of the windlass and capstan, and give the necessary directions for making and fitting them up. *Plate* XI. *Figs.* 1, 2, 3, 4, & 5, are the different plans and sections of a windlass for a ship of about 300 or 320 tons. The strong line A A A represents the deck; *Fig.* 1, a transverse section of the middle of the windlass and pawl-bitt; *Fig.* 2, a semi-longitudinal section; B the half of the pawl-bitt; D the principal piece of the windlass; C the windlass-bitt; E the windlass end; F F and GG the casing or whelps. The principal piece of the windlass, marked D in all the figures, is an octagon, whose diameter at the centre and at the inside of the range-bitt C, is represented by *Figs.* 1 and 4; *Fig.* 1 represents also the pawl-ring, pawls, and pawl-plate, according to the most approved (although not the latest) construction. *Fig.* 4 shews the diameter of the preventer, and the bush and spindle. The ends of the piece D (*Fig.* 2) are bound with the iron hoop marked *a*. The ends of the principal piece of the windlass are cut in square as far as the letter *b*, leaving the projecting part *c* (*Fig.* 3) to go two inches into the range-bitt, which is cut quite true to the circle, and the hoop *b* (*Fig.* 4) driven tightly on it. This circular projecting part on the main piece of the windlass is intended to form a journal on which the windlass would revolve independent of the iron spindle H; and if the spindle should give way, the projecting part would still secure the windlass; and as in riding it tends to prevent those heavy jerking strains from the cable from overstraining and breaking the spindles, it is called the preventer spindle. The hoop *b* is commonly called the preventer or collar-ring; *d* (*Fig.* 4) is a square plate, with a small hole in each corner, about one-half inch thick, made to fit very neatly on the spindle, close up to the round; it is let flush into the end of the windlass, and fas-

tened with the corner bolts *a*, before the spindles are driven in. The spindle H is generally from 3 to 3½ feet long, and its diameter from 2½, 3, to 3½ inches, according to the size of the vessel,—(the rule for its exact diameter is given in our general dimensions and proportions, p. 159); it is driven very tight, half into the windlass and half into the windlass-end, as shewn on the drawing; of course the spindle is square, except at the part which turns in the bush, and is tapered towards the ends. The windlass-ends are commonly made of sufficient length to take in two handspike-holes; they are hooped with the iron hoop *c*, and have also a collar-plate let in and fastened with four small bolts before the ends are drove on to the spindle. And particular care is taken, in marking the place of the holes *f* in the spindle, to bore the same through the windlass and ends, so as to get a locking bolt drove through. F F and G G are whelps or casing pieces bolted or nailed round the windlass and end, to protect the main-pieces from being cut or destroyed by the cable.

Fig. 5 represents the common metal bush and dog-bolt, *h* the bush, *i j* the dog-bolt which supports it. The bush is made with a square groove in the under side, and also up the after part, as deep as to take in 1-3d of the bolt, which is square at that part. The fore side of the bush has a small tenon let 3-4ths of an inch into the bitt, which together with the groove over the bolt and up the after side of the bush, prevent it from moving or working the side way when the ship is rolling.

The dog-bolt *g* is made with a screw and nut on its after end (*see the Fig.*) for the purpose of holding down the after end of a flat plate of iron, the fore end of which fits into a chock on the fore part of the bush. The dog-bolt is commonly drove in slack, or burned in for a good part of the way, (which prevents it from rusting), and locked on the fore part of the knee of the bitts.

Fig. 3 shews the windlass-bitt C, with an improved bush, *l* the foremost piece; it is a little larger than the other, and comes about half an inch abaft the centre of the spindle at the lower side, so that it may not run exactly on the joint of the two pieces of the bush. The upper part of the fixed or fore half of the bush has a small piece taken off, as shewn in the figure, and the after part or half made to fit into it, so that the spindle may go into the bush at the full size. The after half of the bush, marked J, is made short of the fore half, and to natch into it, or bear against two studs, which prevents any upward strain from coming upon the bolts, which are therefore only exposed to a fore-and-aft strain. These two strong bolts pass through the windlass-bitt and knee, and being screwed at their after ends, nuts are put on for securing the after half of the bush. The after part of the windlass-bitts is fixed on by means of two strong bolts forelocked on the fore side of the bitts or knee, as shewn on the plate.

After the above short reference to the plate, we are now prepared to offer a few directions for completing this part of the outfit of the vessel.

The main piece of the windlass should be of the very best British oak, if it can be got, as this, at least in my opinion, is preferable to all others, African oak not excepted.

The piece of timber intended for the windlass must be very carefully examined before it is cut, because from its particular form, after being sawn to the squares and taper, and perhaps some of the handspike-holes cut, should any defect in the piece be discovered

after it is dressed, it will of course be condemned, although its particular shape renders it very unfit for being converted into any other purpose without great waste of material. If, after a careful examination, it is found to be perfectly sound, line it first to a four-square to the proper size. Its length between the bitts is half the main breadth of the ship on deck, and the thickness in the middle 2-3ds of the ship's extreme breadth, taking inches for feet, and parts for inches. It must be kept of equal size in the middle, to the breadth of the pawl-bitt, to receive the cast-metal pawl-ring. The length of the windlass between the bitts, as stated, is one-half the breadth at midships on deck, but may be a small thing less than this, if sufficient room and number of handspike-holes can be obtained. The end diameter, *i. e.* at the inside of the bitts, is 5-6ths of the main diameter. After it is lined to a four-square to these dimensions, it must be sawn and next dressed to an exact eight-square.

Before doing more than prepare the ends, you must have the pawl and windlass-bitts set and squared in their proper positions on the deck. Then take the exact length between the bitts, with a straight batten, at the same time marking on the batten the place of the pawl-bitt, also the most proper and convenient place for the handspike-holes; apply the batten to the piece timber, set off its exact length, and allow for the breadth of the preventer or collar-ring, which is about two inches or so for vessels from 150 to 300 tons. The ends must be neatly squared over from the centre-lines along the four sides, and after they are cut, scrive lines across from the four opposite sides, crossing each other at right angles, and of course their intersection is the centre of the spindle; from this centre, and on the four lines, set off the exact square of the spindle, and with the compasses draw a circle within the square, in order to centre the auger or piercing-bitt by which the windlass is bored to receive the spindle; the same precautions must also be taken in dressing and squaring over the ends, and finding the centre for the spindle in the windlass-ends. It is the most general custom to bore only a little farther into the windlass than the length of the spindle requires, but in some parts they bore the spindle-holes right through from one end to the other, which I think is the best and most convenient method for getting the spindles fitted tight and fair into the windlass, as they can be easily struck out in fitting them, and helped a little if required; whereas, when the windlass is not bored throughout, it is very difficult to get the spindles driven back after they have been put in. Also, by boring the windlass right through from end to end, it prevents any rot from taking place in the centre of the piece by taking out the heart, which in large pieces of timber is generally soft and the first to decay, and communicates the rot to the other parts. Boring the windlass right through has no tendency to diminish its strength, but rather to preserve it.

In several parts of the United States of America, the body of the windlass is made in two pieces, or if the piece be large enough, they cut it up through the middle, and when it is dressed and jointed, let the spindles half into each piece, and bolt and hoop the two pieces firmly together. The advantages of this method are the greater certainty of seeing whether the piece is perfectly sound in the middle or heart before it is farther proceeded with, and that the spindles may be put in more centrically. These advantages are no doubt important; yet as the windlass is no stronger, and as an addi-

tional expense and weight is created in fastening the two halfs together, I think the method of boring the spindle-holes right through to be the most convenient and least expensive.

When the spindle-holes are bored, the handspike-holes are next cut out about 3 inches square, and should never be nearer each other than 15 inches. In marking them off, they must be carefully squared across from all the four principal squares of the windlass, so that the mortises may meet exactly fair through one another. The windlass ends are got on with about this time.

Having already pointed out the form and position of the hoops and bushes, and supposing the windlass made on the ground, and the pawl-bitt placed, the windlass-bitts should be in thickness 1-3d of the diameter of the windlass, and in breadth not less than a whole diameter of the same. To ascertain the place of the mortise for their lower end, strike a direct square line across the deck, at any convenient distance abaft the pawl-bitt. Then, on this transverse line, measure from the centre-line of the ship the half length of the windlass on each side, (the chocks must of course have been previously sunk in to answer this breadth); at these spots lay the stock of a square well with the transverse line on the deck, the blade of the square lying forward at the inside mark of the bitt, draw a line fore-and-aft, which will give the range of the inside of the bitt parallel with the middle line of the ship; at the thickness of the bitts, without this, strike another fore-and-aft line parallel to the last drawn, and it will mark the outside of the bitt; and this being done for both sides of the ship, next find their position in the fore-and-aft direction, that is, their distance abaft the pawl-bitt. Thus, the line of the axis of rotation is exactly a whole diameter of the windlass abaft from the pawl-bitt; therefore, at this distance abaft from the pawl-bitt, strike a straight line across the deck parallel to the first drawn transverse line, and it will represent the vertical to the centre-line of the windlass; next, at the place of the windlass-bitts, set aft from the centre-line the whole diameter of the spindle, which mark will be the after edge of the bitts, when the windlass is to be fitted with a square bush and dog-bolt; but when for two half-bushes bolted above and below, set only 1-4th of the diameter of the spindle abaft the centre-line for the place of the after edge of the bitt.

But here it must be observed, that the rule to place the centre of the windlass, its whole diameter abaft the pawl-bitt, applies particularly to wooden pawls, and only to the cast-iron pawls and pawl-ring when these have been made to answer that distance. This I believe is generally the case; but as every manufacturer is perhaps not aware that the most suitable distance for the centre of the pawl-ring abaft the pawl-bitt is half its diameter, it will be necessary, in fitting the windlass with cast-metal pawls and pawl-rings, to find what distance aft they have been calculated for, by placing the back of the pawl-plate against the coamings of the hatches, or some other straight and steady piece of wood, laying the wheel or ring on its end, and the pawls in their proper place; then measure the distance from the centre of the ring to the back of the pawl-plate, and it will give the proper distance that the centre-line of the windlass should be struck on the deck abaft the pawl-bitt. While the ring and pawls are lying in their exact position, mark the height the pawl-plate stands above the uppermost square, which will

be of advantage when you come to fix the pawl-plate on the bitt. When the mortises are cut out, the bitts driven tight down into the chock and bolted, stretch a line between the bitts at the height and spot of the centre of the windlass, and observe that this centre-line and the inside of the bitts are perpendicular to each other in a fore-and-aft and up-and-down direction. The height of the windlass from the deck may vary a little, according to circumstances, or the peculiar rig of the vessel. Large smacks, in the Leith and London trade, have the centre of their windlass from 20 to 22 inches above deck, according to the intended stave of the bowsprit, which in these vessels runs in over the top of the windlass. But other merchant vessels, such as vessels in the coal trade, and general traders, have the centre of their windlass from 24 to 26 inches above the deck, as at this height it is found that the crew have the greatest mechanical advantage in heaving upon the windlass.

Having marked the height of the centre of the windlas above deck, square it across the inside and outside of the bitts, observing to make them range level across the ship; next, from the cross-line on the inside, strike another, forming an inclination to it, so that it shall radiate exactly from the intended centre of the bush; this being done on the outside of the bitts also, the intersection of these lines must be found by means of two small straight-edged battens, when letting in the bushes, in order to enable you to fit them in exactly to their proper place. The bushes must lie perfectly level across, and range well with each other in every direction, that the spindles may fit close, and run easy in the bushes. After the bushes are properly fitted, the windlass must then be lifted into its place and turned round, to see if the bushes are placed well with its centre, and if it is true of itself; to prove which, nail a batten on the side of the pawl-bitt, reaching aft over the windlass, just touching the highest square; then by turning it gently round, you observe how much the lowest square is off from the batten, and if the distance is more than what the pawl-ring is wider than the diameter of the windlass, the full side must be reduced, so that the centre of the pawl-ring may come fair with the axis of the windlass. The ring should always be 1 or 1½ inches larger in diameter than the windlass, to allow of its being wedged true, so that in turning the windlass the pawl-ring may revolve exactly on its own centre; for if this is not exactly the case, it will go up and down with an eccentric motion, and the pawls will not fit exactly in all the squares, and on this account the windlass will be very deficient, as some of the pawls will be bearing hard, while the others, that should bear equally at the same time, will be slack and quite open. In order to make a good job of the windlass, not only the material, but also the workmanship, both in wood and iron, must be of the very best description, and every part truly wrought.

The inside diameter of the pawl-ring should be one inch at least larger than the windlass, so as to allow half an inch all round for getting it set fair to the centre of rotation, and to allow room for the wedges; but should it happen that a ring cannot be obtained larger than the exact diameter of the windlass, it is the best way, in this case, as soon as the windlass is hung upon the spindles, to turn it perfectly true in the middle upon its own axis; divide it exactly into the eight squares, and dress it to the neat size of the inside diameter of the ring, and then drive the ring tightly on. By this means

it may be brought very near the truth—at the same time it is more easily set correct by means of the wedges. Accordingly, when the ring is put to its place, set it equally off the squares of the windlass, turning it gently round, at the same time having a batten fixed to the pawl-bitt to direct you in placing it true to the centre, in which position you must fix it by a number of temporary wedges or slips, placed on the four opposite squares. The ring being set true with these, they must be driven pretty tightly in; then prepare to drive in those on the other four opposite squares for a full due. The proper wedges must be made of very dry hard wood, two for each square, and driven one from each end of the ring on the same square; they should be in breadth equal to the pane, and tapered off very neatly, so that both points may come through to the opposite sides. They should never be made so as to bear hollow, but be solid, and equally tight throughout the whole breadth of the ring. Fit all the wedges of the four squares before beginning to drive any of them tight, which you must do by driving only a little upon the wedges of the opposite squares at a time, so that you do not alter the position of the centre of the ring during the time of driving the wedges or slips. When the first four squares are wedged sufficiently tight to keep the ring from shifting, take out the temporary ones on the four opposite squares; then fit and drive in moderately tight the proper ones. Try the windlass round, observe the revolutions of the ring, and if it present an eccentricity from the true rotation on the spindles, this may be adjusted by setting up the wedges to an equal degree of tightness. If the windlass has been made for some length of time, and exposed to the drought, the wedges must not be driven very tight, otherwise there will be some risk of the ring breaking by the expansion of the windlass when it is exposed to wet or dampness.

When the ring is properly fixed, the next thing is to fit and fix the pawl-plate on to the pawl-bitt. When it is temporarily held to the pawl-bitt, at the exact height, or as near thereto as possible, try in three of the pawls into the ratchets of the ring, the uppermost, the square or level pawl, and also the under one; and should the square or level pawl fit hard, while the other two are slack, the plate must be let a small thing back into the pawl-bitt; at the same time, great care must be taken that it is not let too far back, which would cause the pawls to stand off their proper centre, and point too much towards the centre of the ring, in place of bearing at a tangent to its circumference on the square of their ends. If the uppermost pawl is close, and the under one open from the ratchet, the plate must be raised a little, and *vice versa*.

The plate should be made to fit very solidly against the pawl-bitt, otherwise it may be broke with a small jerk or strain on the windlass. When the plate is placed and bolted on as near its true place as possible, and the pawls set in, if they are not all bearing fair at the proper parts of the revolution of the windlass, the ends of those that are long must be pared off with a cold chissel, and the whole made to fit to their exact and proper bearing. This should be attended to after the vessel is launched into the water, as there are few or no ships but what will make some little alteration in this respect, after they are fairly afloat for a little time.

After the pawls are fitted, the casing of the windlass is next put on. It is commonly oak or elm, as this stands well, and bears the chafing and cutting of the cable better

than most other kinds of timber; but as it nevertheless wears fast, such vessels as are exposed to much anchorage have commonly the working side of the windlass covered with strong sheet iron, or pieces of cast iron of the same form as the casing, on four of the opposite squares. In large smacks, there are two pawl-bitts, and the windlass is accordingly fitted with two pawl-rings and pawls, the bowsprit coming in between them. In this case, the rings and pawls are rather narrower and lighter than when there is only one employed; also the windlass for large vessels should have three sets of pawls, one in the middle, and one at each end attached to the range-bitts.

Improvements on the Windlass.—The most important improvement on the windlass is the cast-metal pawls and pawl-rings. Before its invention, the pawls were made of good oak timber, well seasoned, and the ratchets were cut out of the body of the windlass into eight principal wood locks or ratchets. In the year 1786, Captain Stephen Wright obtained a patent for applying iron axles or spindles and iron pawls (stopping at every 16th square) in the middle and at the windlass-bitts. About the same time, Mr. Moore of London obtained a patent for his balance-pawls.

Sowerby's Patent Pawl consists in forming the pawls all of one piece, as represented by *Figs*. 12 and 13, *Plate* XI.; also a cast-metal riding chock. A is the toothed rim, or cylindrical ring, B the pawl or back-plate, C the working-pawl, D the riding-chock, E the riding-chock shoe, bolted to the pawl-bitt and to the deck through the piece of timber F. *Fig*. 12 is a side view of the apparatus, as when getting the anchor; *Fig*. 13 shews the position of the pawl and riding-chock, supposing the vessel at anchor. There is also a lever or crow-bar for raising the riding-chock into gear with the rim, through the opening O, when wedging it up; also for starting the wedge W before heaving. When the windlass is hove round (*Fig*. 12), the working-pawl rises and falls perpendicularly in the succession of the teeth on the pawl-ring, thus pawling at once every tooth on a considerable portion of its circumference.

Before rinding or veering the cable, the riding-chock is raised by a crow-bar, the wedge W being at the same time driven in, until the chock is firmly geared with the ratchets or sheath of the rim, as shewn by *Fig*. 13.

The advantages which the patentee supposes this invention to possess over the common pawls are—1*st*, The working-pawl offers a more solid resistance than a series of pawls such as are commonly used, whilst its action against the pawl-bitt is nearer the deck. 2*d*, It cannot be upset, as, from its wedge-like form, it becomes the more firmly fixed as the strain increases; consequently the anchor may be got by it, when with the common pawls it would be most hazardous to attempt it. 3*d*, It is not deranged by screwing, or otherwise straining the deck-timbers, but falls alike, however the body of the windlass is raised or depressed. 4*th*, If the cable ride, or a handspike get fast, and if it be required to run the windlass backwards (*Fig*. 13), it may be done instantly by raising the pawl, which may be as quickly replaced. 5*th*, For riding or veering, the windlass becomes a complete fixture with the pawl-bitt and decks, and cannot be moved by any jerk or strain whilst they remain fast. It is not only supposed much more effective in supporting and securing the windlass than the wooden chocks now in use, but also in preventing the least reaction or working of the windlass, as it is secured alike in every direction.

The original cost of the whole apparatus is said to be much less than that of the common pawls and riding chocks; it requires less time and art in fitting, and it is not liable to get out of repair.

The following are the inventor's directions for fitting it:—

The Windlass Body, Bitts, and Necks, are fitted in the usual way.

The Pawl-bitt.—Its after side must be perpendicular, and distant from the centre-line, equal to about three-fourths of the inside diameter of the rim.

The Rim, or Cylinder, must be firmly and accurately wedged upon the windlass body.

The Pawl and Back-plate.—Place the pawl on the top of the rim, and turn the windlass backward, until the back of the pawl is parallel to the bitt, or to a plumb-line; and if the pawl-bitt be at a greater distance than the thickness of the back-plate (as in vessels which have formerly had the common iron pawls), it must be adjusted by facing a piece of timber on the after-side. This done, bolt the back-plate to the bitt, the ends of its side-flanges being opposite the centre-line, so that when the pawl is in its place, and a strain upon it, its distance from the under side of the bracket may be equal to about one-eighth of the inside diameter of the rim. Its low end must fit close against the back-plate, and its top tooth must be a little short of its bearance against the teeth on the rim. The working-pawl being thus properly fitted, raise

The Riding Chock with the wedge W, until the point of the wedge is at the middle of the opening O. Then raise the whole against the after-side of the pawl-bitt, until the teeth of the riding chock gear close with the teeth of the rim; taking care that the shoe be so far aft that the back of the riding-chock, when in gear, be close against the shoe, which will generally require a thin piece of wood between the shoe and the face of the pawl-bitt; and also that the wedge be not slack at the thin end. The timber F must then be fitted between the shoe and the deck, and the shoe bolted to the pawl-bitt, and through the timber to the deck.

If the work be correct, the chock will gear easily, the wedge requiring but a blow or two with the handspike, when the windlass will be so firmly held as not to be moved either way. The wedge may be instantly and easily started by a stroke of the lever, which should be made fast to the pawl-bitt, as most convenient.

N. B. The inside of the pawl-plate and back of the pawl should occasionally be rubbed with black lead.

The ingenuity of this invention is considerable; yet it appears evident that it is not altogether complete. From the wedge-like form of the pawl, and the want of a stopper on the pawl-plate, it will throw a very severe and unnecessary strain on the windlass and pawl-bitt, by tending to wedge the former aft from the bitt. This of course could easily be prevented by having a projecting pin on the plate.

Yett's Patent Apparatus, for securing the windlass when at anchor, is so generally known, that any description of it here is unnecessary.

The first idea of increasing the power of the windlass beyond that of the common handspikes, or windlass-bars, was suggested and tried by Mr. William Hutchinson of Liverpool, and is described in his Treatise on Practical Seamanship, about the time of

Wright's improvement. Mr. H. proposed, when very great strains were to be hove with the windlass, to have one or two long bars extending across the windlass, with two ragged wheels; and when the square and all the pawls are properly down, the middle of the bar to be laid on the windlass close by the bitts, right above the top-tooth of the ragged wheel, with the fore-end down to the deck, so that the after-end of the bar will be so high that a man may reach it from the deck; and having one or two men at each end of this bar, those before the windlass will be lifting it up with all their power, while those abaft the windlass will be pulling down with all their might. The windlass may thus be hove round, when perhaps it could not be started one pawl by the people swinging on the common handspikes.

The power of the windlass is estimated thus, (and the principle is the same as the wheel and axle, formerly explained in our treatise on Mechanics):—As the semi-diameter of that part where the cable is wound round, is to the semi-diameter of the circle described by that part of the handspike where the medium weight of the men is exerted; so is the weight of the crew to the power of the windlass, or weight of the anchor or body which is to be raised by it.

As a means of aiding or increasing the power of the windlass, a large wheel is now fixed on the spindle at one end, and a large crank handle, on the shaft of which is fixed a pinion working into the teeth of the wheel, which is hove round in the same manner as the winch. This is chiefly used in getting the anchor in large vessels.

Another patent has been lately obtained for effecting the same purpose by Keenlyside and Company, Newcastle. This improvement is represented by *Figs.* 14 and 15, *Plate* XI. B is the pawl-bitt, C the windlass-bitt, D the body of the windlass, E a small windlass above the main one, F a chain passing round the main windlass, and over a ratchet-wheel E (*Fig.* 15); so that when the upper spindle is hove round, the windlass is turned in the same direction with an increased power of 4 to 1.

Capstan.—The capstan is a machine similar in principle to the windlass, and like it used for raising great weights. In large vessels it is used for raising the anchor, in place of the windlass, but is more frequently employed in hoisting out the cargoes in merchant-vessels, or such like purposes, these having a windlass also. There is also another machine used on board ship, called a *Crab*, for the same purpose, and differing from the capstan only in this respect, that the latter is stationary in one place of the deck, while the crab is made so as to be shifted to any required place. Both these are in principle a vertical windlass, the bars or levers by which they are hove round being placed horizontally in the upper part or head of the capstan. The rope to be worked is taken two or three times round the lower half of the body of the capstan, and at this part the pieces called the whelps are made with a certain projection, to prevent the rope from rising too high, and thereby straining the spindle, which is fixed in a strong beam or chock in the deck, and around which the capstan revolves. *See Plate* XI. *Figs.* 6, 7, 8, & 9, the last of which represents the capstan in a finished state. *Fig.* 6 is a ground-plan of the barrel, whelps, spindle, and pawls; and as the capstan is commonly placed a little abaft the after hatchway in ships and brigs, suppose M to be the after part of the coamings of the hatch, N a piece of wood fitted against the coamings, and bolted down to the deck for

supporting the fore-end of the pieces, O, which are made to turn round upon the bolt which fastens down their fore-end; they are called the pawls, and are used for preventing the capstan from recoiling, or for fixing it against any particular strain. B is a strong iron spindle projecting up through the deck,—(*see* also *Fig.* 17, where the same letters are used for the corresponding parts); C the barrel or main piece of the capstan, which revolves round the spindle; its horizontal section is bounded by 10 sides, on five of which are bolted the pieces D D, called the whelps.

Fig. 7 represents a vertical section of the capstan. A A A is the edge of the deck; K the end of a beam at the after-end of the hatchway; L L a chock or strong piece of timber fitted between the beams, into which the spindle is secured; M M the coamings of the hatch; N the chock for fixing the pawls against; O the pawls, C the barrel, D the whelps, E the coags between the whelps; *d d′*, at the top and bottom of the barrel, the edge of an iron bush; *b b* a flange on the spindle; *l* a strong coatteral or fore-lock, for securing the spindle tight down into the chock; *h* a strong iron plate over the head of the barrel, against the under side of which the point of the spindle bears, and thereby supports the whole weight of the capstan; *r r* a strong iron hoop around the lower end of the barrel; P the drum-head, made of two thicknesses of wood, and of four pieces altogether, two in the lower, and two in the upper half, the joints of which cross each other at right angles; *m m* the bar-hole or mortises; *i i* iron rings let into the upper and lower side of the drum-head; *j j* the bolts which pass down through the rings and fasten the drum-head together; *a″ a″* hoops for holding the drum-head down to the barrel.

In this figure we have drawn the drum-head with ten panes, but it is commonly made with eight panes, having a bar into each, eight bars being supposed sufficient in most cases. Sometimes the drum-head is made circular on the upper part, and octagonal below; others again have it all turned to a fair round.

The first thing to be done, after determining on the size and form, is to seek out a piece of good oak for the barrel. Its length is generally about 3 feet 4 inches, and diameter 3-7ths of the ship's extreme breadth, taking inches for feet and parts for inches. Thus suppose the ship's extreme breadth 28 feet; $28 \times 3 = 84$, and $84 \div 7 = 12$ inches for the diameter of the barrel. (*See* General Proportions, page 159.)

Having found the dimensions of the principal parts of the capstan, the barrel may be lined and sawn to its proper form, which (whatever may be the shape of the drum-head) answers best to be a prism, having ten equal panes or sides. The easiest method of lining this figure in practice, and which requires no calculation or setting off of angles, is the following:—Suppose *a b c d* (*see Fig.* 127, *Plate* VII.) to represent the end of the rough piece of timber intended for the barrel, first square it up to 12 inches by 13, as the diameter *a b* will exceed that of *b c* a little. First side off the piece *a l m b*, and next the piece *b p c*; square off *a b*; square and cut both ends of the piece to the exact length; strike a middle line along the barrel, and draw the ends, as *e f*; next draw the line *o p*, bisecting *e f* at right angles; and from the intersection of these lines as a centre *i*, sweep a circle equal to the whole diameter of the barrel; then take 1-7th of the semi-diameter *e i* in the compasses; set it on any side of the centre-line *e f*, as *i j*; next

take 1-3d of the whole diameter in the compasses, place the one point in *j*, bring the other to intersect the line *e f*, as in the point *k*; then will the distance *k i* be the breadth of the panes of your ten squares. Set this distance equal on each side of the point *e*, on the side *a b* of the piece—you will then have the points *l* and *m*; turn the distance *l m* all round the circle on the end of the piece; draw from point to point, which will give the ten sides of the barrel marked off, the other end being divided in the same manner; after the barrel is thus lined on the ends, it may be sawn exactly to the size.

The pieces for the head should be provided as early as possible. They should be sound, well seasoned pieces of timber or plank cut near to the proper size, and left in some dry place where they will be fully exposed to the drought, until such time as they are to be put together; for when the capstan is finished, the head part is most exposed to the weather, and from the manner in which it is cut for the bars, it is very liable to split and cling. When the head-pieces are thus prepared, next proceed with the whelps. These must also be solid pieces of timber, quite free from rents and sap-wood. Having procured pieces for this purpose, side them up to the thickness, and dress them all out to the mould; square and cut them to the neat length; place them alongside of each other, with their lower ends quite fair to a square across them; set off the exact height of the coags from the lower end on the outside ones; then with a straight edge scrive them across, and you will have the size and position of the coags. Draw in the outside edge of all the whelps; apply a square from the inside edge of the whelps to the scrive on the outer edge; square this across their sides, and proceed to cut out the dovetail chack for receiving the ends of the coags; and it is better to do this before the whelps are bolted on the barrel. But before bolting on the whelps, get on the hoop on the lower end of the barrel. Be very particular in drawing the centre-lines for the whelps on the sides and ends of the barrel; a centre-line must also be drawn on the ends of the whelps, so that when they are laid on the respective panes of the barrel, they may come exactly fair to the centre of the pane. The barrel must be bored up through to the size of the diameter of the spindle, or rather a small thing wider, so as to allow the capstan to run freely. When the whelps are all placed on their respective panes of the barrel, put a chain round the whole; set it tight with wedges, to hold the whelps firmly to the barrel. Observe that they are all standing exactly to their proper places, and fix them with a couple of nails at their upper ends, and with a small bolt, about three inches from the lower end; also put three small treenails in their middle, two between the lower and the middle coag, and one a little above the latter one (see *Plate* XI. *Figs.* 7 and 9.) When the whelps are all fastened to the barrel in this manner, fit in all the coags, and fasten them with a small bolt and nail at each end. Care must be taken that the bolts through the coags and whelps into the barrel, are short of the hole for the spindle, which is bored when the barrel is begun with. After the barrel is thus far ready, begin and dress the pieces for the drum-head to their exact thickness and shape, and joint them together, beginning with the lower pieces first. Lay the two pieces together; mark the size of the square mortise for the head of the barrel; also draw the situation for the bar-holes. These are generally from 3-5ths to 2-3ds of their depth taken out of the lower half of the drum-head,

and the remaining part out of the upper half. The handspike-holes are commonly from 4½ to 6 inches inwards to the centre of the drum-head—about 3 inches square at the outer part, and 2⅞ inches square at their inner end. The mortise in the under side of the drum-head for receiving the head of the barrel, is about 1-3d of the diameter of the drum-head the one way, and 1 or 1½ inches less the other. The size of this mortise, however, and also the depth of the bar-holes, should, if possible, be contrived so that two small bolts can be put through the edges of the two lower pieces of the top (to hold them together), clear of the mortise, for the barrel, and the holes for the bars or handspikes. This may be easily obtained, if you consider it at first, when drawing out the sketch plan of the capstan. When the two lower pieces of the drum-head are bolted together, mark off the neat size of the bar-holes, and chack them out to the exact depth; but observe to leave the cutting out of the mortise for the head of the barrel until the two halfs of the head are completely fastened together, as it can then be done more perfectly, and with less risk of splitting. When the lower half of the head is thus got on with, proceed to the upper half; lay the pieces upon the lower half in their proper position; fasten them down to the lower pieces with two nails in each, driven in temporarily, so as to be easily drawn out; then scrive in all the bar-holes to to correspond exactly with those in the lower half; take off the upper half-pieces, and having cut them out, put it on again, and proceed to fasten it down for a full due. The holes for the bars should be all exactly square, and as near as possible of the same size. For the better certainty of lining them out correctly, you should shape a piece of wood exactly square in the edges, and to the size of the intended bars, for a mould with which to draw by all the holes. When the bar-holes are cut out, the upper and lower half of the head are to be fastened together with a few nails or small bolts, keeping them clear of the handspike or bar-holes, and the place of the ring, which is next to be sunk neatly into the head, one in the upper side and one in the lower side. In laying on the rings to draw them by, also attend that none of the through-bolts will come in the way of the bar-holes. When the rings are let into the head, drive and clench the bolts, and it is then ready for fitting down on the head of the barrel. The square on the top of the barrel, which fits into the mortise on the under side of the drum-head, stands three inches up above the ends of the whelps, but the mortise in the head is cut 4 inches deep; and when the head is fitted neatly down to the shoulders of the tenon on the barrel, take the compasses and scrive on the under side of the head, all round the outside of the barrel and ends of the whelps; take off the head and chack out all round by the inside of the scrive 7-8ths of an inch deep, flat through to the square, so that when the head is again put on, it may natch that much down, and have a complete hold of the whole barrel, resting on the outsides of the same and end of the whelps. Before the head is put on, the bush must be sunk into the top part of the barrel, and the plate for bearing the weight of the capstan on the end of the spindle properly fitted and secured down to the barrel. This method of hanging the weight of the capstan on the top of the spindle, is more frequently used than the following, which, however, is supposed to be the best, only a little more troublesome; *i. e.* In place of having the spindle so long as represented in the drawing (*Plate* XI.), kept 7 or 8

inches short of the top of the barrel; then opposite to the point of the spindle, allowing the lower end of the capstan to be a little clear of the deck, cut a flat mortise-hole through the barrel to take in a plate of iron about 2 inches broad and half an inch thick; then drive through this plate, so that the top of the spindle may rest against its under side. This makes a very secure job, as it cannot get started off or damaged by any weighty thing falling on the head of the capstan. In the other case, this would be apt to start the plate, and of course the capstan would settle down. But also, if it is desired to prevent the capstan from rising up on the spindle, you have only to turn a groove or a small natch round the spindle, a little below the bush, and put a small cutter through the barrel, bearing with one edge in the natch.

With respect to fixing the pawls, fit and bolt a solid piece of oak down to the deck, and against the coamings of the hatch. Before fastening it down, the deck under it should be served over with a coat of warm tar and flannel, or boat-builders' blair, to prevent it from rotting under the chock; then fit the fore-ends of the pawls into a circular joint, so that they may turn on the bolt, and at the same time bear the whole strain on the chock or piece, which is firmly bolted down to the beam for that purpose.

The principal construction of the common capstan being thus explained, an inspection of the drawings will be sufficient to assist the young shipwright in completing the machine. The power of the capstan may be estimated in the same manner as the windlass, as before noticed.

Messrs. J. Keenlyside and Company, whose increased power for the windlass has been noticed, also propose the application of the same principle to increase the power of the capstan, by fixing the drum-head to the spindle, so that the spindle is made to turn round with the head. On the lower part of the spindle, at the deck, is fixed a kind of crank, which works into the interior circumference of the lower end of the capstan, diminishing the velocity of the barrel to the head in the ratio of 4 to 1, so that the power is increased in the same proportion. The ingenuity of this invention deserves particular notice, and must be considered a very great improvement on the capstan.

The Winch.—This is also a machine on the same principle as the two we have described; but instead of being hove round with handspikes, it is turned round by crank-handles. The winch is much smaller than the windlass or capstan, and only intended for light purposes, such as warping the vessel from one place to another in harbour, or hoisting in or out light goods, or setting the sails, &c. There are two kinds, the single and double winch, the latter being contrived so that the power can be increased beyond that of a single winch. Both kinds are simple in their construction.

The *single-winch* consists of a horizontal iron spindle, crossing the middle of the deck, supported at a certain height above the same by two stout pieces of wood, called the winch-bitts. The spindle revolves in two bushes fixed on the after-side of the bitts, which are commonly placed about 6 or 6½ feet apart, as the other conveniences on deck may require. On the ends of the spindle, which projects beyond the outside of the bitts about 14 or 18 inches, are fixed circular pieces of hard wood for taking the rope round. These pieces are commonly called the winch-ends, or drums. On the end of which, next the bitt, is fixed a ratchet-wheel; and a pawl, for working in the same, is attached

to the bitt. On the extreme ends of the spindle are fixed the crank-handles, at which the men exert their force in turning it round.

The *double-winch* has two spindles, the one above the other, with two ends or drums. There is a small pinion fixed on the upper spindle, which slides in the bushes, and is accordingly thrown in or out of the gear of a large wheel fixed on the lower spindle. The handles are fixed on the upper spindle, which answers best to be about 3½ feet above the deck. Although the winch has been long used for land purposes, it is only lately that it has been generally fitted up in vessels. It is extremely useful in small brigs, as the capstan frequently occupies too much room on deck; in large smacks, also, the double-winch is of great utility for heaving up their heavy sails, and taking in and out the heavy articles of the cargo.

Figs. 10 and 11, *Plate* XI. is a drawing of the double winch calculated for a smack of about 200 tons. The winch commonly stands between the main hatch and mast in smacks, and before the main-mast in brigs and schooners,—(*see Fig.* 10, where A A is the deck, B B the winch-bitts, C the upper spindle, D the lower spindle.) But a bare inspection of the figure supersedes the necessity of any farther description.

Between the pinion on the upper spindle, and the wheel on the lower one, is placed an intermediate one, sliding in an arbour. This is introduced merely to keep the two spindles separate, to allow the heel of the bowsprit to run in between them. Sometimes, however, and which is found equally convenient, the heel of the bowsprit runs in over the upper spindle; and the construction, in this case, is shewn by *Fig.* 11. The double-winch (*Fig.* 10) is thrown in or out of gear by sliding the intermediate wheel on the arbour, and (*Fig.* 11) by sliding the upper spindle in the bushes, the lower spindle being at the same time secured with pawls.

The power of the single-winch is commonly about 4 to 1, that is, the drum or winch end is 1-4th of the diameter of the circle described by a revolution of the handle, and is estimated thus:—As the semidiameter of the drum or winch-end, adding the thickness of the rope, is to the length of the crank of the handle, so is the power applied to the weight which may be raised; and when a rope is taken to the double-winch, or lower barrel, the power is increased commonly as 12 to 1, that is, until 1 lb. upon the handle balance 12 lbs. suspended from the circumference of the lower barrel.

$$\left.\begin{array}{ll}\text{Thus, if the sweep of the handle is} & \text{16 inches,}\\ \text{The radius of the pinion} \quad . \quad . & \text{4 inches,}\end{array}\right\}\text{ it produces a power of 4 to 1.}$$

$$\left.\begin{array}{ll}\text{Then, let the wheel on the lower spindle, and on} & \\ \quad\text{which the pinion acts, be} \quad . \quad . & \text{27 inches,}\\ \text{And the barrel of the lower winch} & \text{9 inches,}\end{array}\right\}\text{ this will produce a power of 3 to 1;}$$

and hence a power of 4 to 1, working upon another of 3 to 1, produces $4 \times 3 = 12$, a power of 12 to 1; and deducting 1-6th of the whole for friction, we shall still have an efficient power of 10 to 1.

Rudder.—Having determined on the dimensions of the different parts of the rudder, according to the rules given in our general dimensions and proportions (*see* p. 160), the first thing is to procure suitable timber. The principal piece, called the rudder-post, should be good sound oak, of sufficient length to reach down to the lower end of the

rudder; it should also have a particular cast or turn aftwards from about the place of the lower part of the rudder-case, so that it will come into the middle of the rudder at the lower end—at least it should have this cast aftwards so far as to take a good solid piece on its fore edge, so as to form the fore part of the rudder, and save the main piece from being cut or wounded by letting on the rudder-bands. Sometimes this is not attended to, and the consequence is, that the main piece, extending down quite straight, is much weakened and reduced by cutting for the gougeons and bearding, to allow the rudder to go over. But another advantage of having the main piece with a cast backward into the middle of the rudder towards the bottom is, that it eases or throws less strain on the bolting.

The main piece, or rudder-stock, should be sided nearly of an equal size, from the top down to where the back-pieces or toblets, or tallants, for making up the proper breadth of the rudder, are fixed; when sided, it is moulded the fore-and-aft way, and the place of the bands marked with chalk. The piece for making up the fore edge to a straight line is then put on; this piece should be quite free from shakes, otherwise it is apt to split with the bolting or cutting out for the bands. When this piece is fayed on and fastened, taking care to put the bolts clear of the cutting-out for the bands, dress it and the main piece completely out of winding the side way, and to the proper thickness; line the fore edge quite straight from top to bottom, and dress it square to the same. About this time the braces should be fitted on to the stern-post. I have before given the rule, and a table for the number and size of the rudder-bands, (*see* p. 162). With respect to their position on the post, place the lower one about 18 inches or 2 feet up from the bottom of the rudder, the one next the counter about the height of the wing-transom, and the others so that the distances between them shall be gradually diminished downwards, as may be seen by inspecting the plans of the 400 or 500 ton ships, in which they are considered to be well placed. (*See Plates* XXIII & XXIV.) The place of the rudder-bands being marked on a long batten, apply it to the stern-post, and scrive them in; also apply the batten on the fore edge of the rudder, and race them in on it also. When this is done, turn the main piece with the after edge upwards, and fit on all the after pieces which may be required to make up the proportional breadth of the rudder, and bolt them through all, taking care, as before noticed, to place the bolts clear of the bands. The bolts should not be less than 1-8th part of an inch in diameter for every six inches of the breadth and thickness of the rudder, and placed not more than two feet apart. If the rudder is not properly bolted, so that it works at any of the joints of the different pieces, this will cause an additional strain upon the fastening of the straps, which will soon become loose, and expose the pintles to greater strains, and make them wear faster than would otherwise be the case. When the rudder is properly bolted together, and the tiller-hole cut out, next proceed to take off the bearding, *i. e.* the angle to which the fore edge of the rudder is penned up and dressed-to, so as to allow it to traverse upon the bands, and go over to the proper angle assigned for steering the ship. (*See* observations on the rudder, p. 165.) Shipbuilders differ in opinion on the bearding of the rudder: some consider it preferable to take one half of the bearding off the stern-post and the other off the rudder—others to take

the whole off the rudder; at all events, there must always be as much bearded off from one or other, or both, as to allow the rudder to go freely over, to make an angle of about 36 degrees from the line of the keel prolonged, which is sufficient to produce the greatest effect in steering the vessel.

Those who are in the practice of bearding the stern-post, consider that it is of great advantage by way of saving the strength of the rudder-stock, which may be true in some cases, such as when the piece is small and straight; but even then, the advantage is not near so great as appears from a superficial view, because, whether you take all the bearding off the rudder or not, the same depth of wood-lock or chest must be cut out to receive the crown of the brace. The only way to save the strength of the main piece is to have it with a cast into the middle of the rudder, so that a filling piece may be put on its fore edge. The bearding of the stern-post in small vessels is of very little use, and may therefore be disregarded; but for ships of 300 tons and upwards, it may be done with advantage only in the following manner; that is to say, the stern-post should be bearded from the top down to the load-water line, and from that to the keel it should be left square, and the bearding taken wholly off the fore part of the rudder; for it is evident that the same opening for allowing the rudder to traverse must be made, whether it is taken off the rudder or off the stern-post, or off both. It may be easily demonstrated, that whatever is taken off the stern-post will bring the water, which is gliding along as the ship is sailing, to strike with greater effect upon the fore edge of the rudder, as, in this case, the fore part of the rudder being nearly square, the water impinges upon a perpendicular surface, and of course tends to retard the velocity of the ship. On the other hand, when the stern-post all under water is left square, and the bearding taken all off the fore edge of the rudder, the water is not led to strike it so directly, and the fore edge being more sharply pinned up, it has less effect in retarding the motion of the ship; but in both cases there will be more or less of vacuum, or eddied water, carried along between the back of the post and fore edge of the rudder. To obviate this as much as possible, and to bring the water smoothly to the rudder, I would recommend Captain Timbrell's method of flaps being hinged on the after edge of the stern-post (*see* p. 164), and the bearding to be taken all off the rudder. The fore edge of which being supposed dressed square, set 1-3d part of the thickness down each side thus,—if the rudder is 12 inches thick at the fore edge, 4 inches down the side will be the deepness of the bearding-line, which may be also found in this manner: Take 3-5ths of the thickness of the rudder in your compasses; and place the point of one leg in the middle line, the other will reach over the corner down the side, to an extent which will be nearly 1-3d of the thickness as before. This last method is more convenient if the piece should be weaning on the corners.

By bearding the fore edge of the rudder to this extent, it will go over 34½ degrees, supposing the motion to proceed from the fore edge of the centre of the rudder. But as the centre of motion is the centre of the pintles, and not the fore-edge or centre-line on the same, the rudder will traverse 36 degrees each way from the centre-line of the keel prolonged. As the centre of rotation is the centre of the braces or pintles, the fore edge of the rudder does not require to be wrought to a sharp point or pane, but

may be left one-half or three-fourths of an inch flat, or so as to form the same round as the pintles.

Nothing farther is done to the rudder until the braces are all properly fitted and bolted to the stern-post. In doing this, the stopper or blid-brace is the last fixed (for hanging the weight of the rudder), for the conveniency of obtaining a line to pass down through the other braces, so as to get them completely fair and centrical to each other.

In letting in and fitting the bands upon the rudder, great care must be taken to keep the pintles quite fair and straight with the centre-line in respect to the side way, and also fair and straight with each other the fore-and-aft way; so that the rudder may revolve or turn, as it were, upon an imaginary line passing down through the centre of all the pintles and braces.

Directions for fitting Rudders, with the upper end fitting close into the rudder-case in the counter.—Having described the construction of the common rudder, we come next to the improved kind, the principle of which is laid down in page 163.

It is chiefly large two-decked ships that require to be fitted with the improved rudder working close in the counter, these being generally steered by a tiller working under the main or cabin deck; and as the rudder-case does not come up to the poop or upper deck, of course the adoption of this improvement is of necessity required for the safety of the vessel. Small vessels, where the rudder-stock and case goes right up to the deck, do not require it, as no danger can result from any water that might be thrown up the rudder-case by a wave catching them under the counter. Nevertheless small vessels may be, and are sometimes fitted with rudders of this kind, when it is wished to keep the deck as dry as possible for the comfort of passengers, or the like.

Accordingly, it should be determined, in drawing the plan, whether the vessel is to have a rudder made in this manner or not, and the stern-post drawn to answer the same. For the rudder to work close in the counter, the stern-post must be straight from the keel up to about the height of the wing-transom; and from that to the lower part of the counter it must be turned forward equal to the half diameter of the rudder-stock, (I have already given rules for the size of the rudder-stock when made square, and also the rules for proportioning the strength of round to square timber, page 50, which will be sufficient to enable us to find the diameter of a round of equal strength to a square piece of a given size), deducting the half diameter of the pintles, as the centre of motion is their centre, which is their half diameter abaft the stern-post. Thus, supposing the diameter of the rudder-stock to be 14 inches, and the pintles $2\frac{1}{2}$ inches, the post must be taken $5\frac{3}{4}$ inches forward at the counter, and worked out hollow to the round of the rudder-stock, and from that up to the top, also hollowed out to the circle of the rudder-stock. Now here observe, that when we say the stern-post must have a cast forward at the counter equal to half the diameter of the rudder-stock, minus the half diameter of the pintles, we refer to the centre and not the sides of the post at the same place, as these must be as much abaft as is required (according to the thickness of the stern-post) to form the circle of the rudder-stock. The after side of the stern-post must be

worked out hollow, to fit the round of the head of the rudder-stock. The most correct method of doing this is to take a straight batten the exact size of the pintles, having the upper end extending above the straight part of the stern-post made quite round; and when you have fastened this right up the centre of the stern-post, take a piece of board, and draw with the compasses a circle equal to the diameter of the pintles; next, with the same centre, describe a circle equal to the diameter of the rudder-stock; cut the board off to this outer circle, and also cut out the small circle to fit on the round part of the batten; the board need not be a full round, the semicircle being sufficient, and the semidiameter of the small circle will also be sufficient to apply against the round part of the batten. Being thus provided with a guage, begin and hollow out the after part of the stern-post to fit the fore side of the rudder-stock, which, by trying your round board into the hollow, keeping the small semicircular natch against the batten, you may do to the greatest nicety. After this is done, the rudder-case, if the counter be in such a state of forwardness as to allow it, may be fitted. The fore part, which joins each side of the post, must also be made very true to the circle, but the after part may be made two inches wider, or so as to allow the rudder to ship with ease, this opening being afterwards made quite close, by fitting a circular piece neatly round the after side of the rudder-stock, and nailing it firmly to the counter.

In placing the braces to the post, the uppermost one must be put a very little below the spot where the head of the stern-post begins to fly forward.

In fitting rudders to work close in the counter, the neat size of the rudder-bands and pintles must be first ascertained, in order to get the true centre for working out the round in the stern-post, as just described, otherwise it is mere chance if it fit exactly in the round. In order to line out the rudder-post, it will be necessary to make a mould to fit on the after part of the stern-post, to obtain the exact form of the fore part of the head of the rudder-stock.

As it sometimes happens that the tiller may be fixed into the stock considerably above the uppermost rudder-band on the stern-post, it is necessary in that case to have a spindle fixed into the head of the stock or rudder-post, above the tiller, to work in a bush fixed in a wood or iron frame for that purpose, as this will make the rudder-head work perfectly steady, and prevent the friction on the sides of the casing. In vessels exposed to take the ground, the top spindle must be made of sufficient length to allow the rudder to lift as far as what is allowed by the lockings on the outside.

On Working the Rudder-post.—The fore part at the place where the after side of the stern-post meets the counter, must be completely rounded; from which, down to the uppermost band on the stern-post, the rounding will gradually diminish in form of an inverted cone. The head of the stock must be rounded down on the after side (say 8 or 10 inches below the counter), to allow the rudder to lift without jamming or bruising the after side of the casing.

From what has now been said respecting this kind of rudder, it may with safety be presumed that any good shipwright will have no difficulty in executing the whole.

Having given some directions for constructing the two kinds of rudders which are in most general use, I shall next notice another method of fitting the fore edge of the

rudder, so as to work into a hollow down the stern-post, which I have somewhere heard called Even's patent rudder. I consider the method as being excellent, and of great advantage to some classes of shipping. Whether it is a patent invention or not I cannot say (having never seen any descriptions of it), yet as nothing tends more to bring inventions or improvements into use than a general understanding of their advantages, and the methods of executing them in practice, the following directions are herewith given.

In the common rudder, there must always be an opening between its fore edge at each side, and the after edge of the stern-post, formed by the bearing, equal to 1-3d the thickness of the rudder-stock, to allow the rudder to go over in steering the vessel; and, as before demonstrated, the eddied water carried along in this opening, and the impulse on the fore edge of the rudder, tends considerably to prevent the vessel sailing and steering well, to obviate which, Captain Timbrell's improvement is adopted on many vessels' rudders, and some slight improvement on the sailing of vessels lately fitted with this improvement has been observed. The copper flaps, of course, soon either wear themselves or the copper on the rudder, on which they rub, and are liable to be easily damaged. The method of working the fore edge of the rudder into a hollow in the after edge of the stern-post, effects the same object. It is done on the principle of the half-moon or table-hinge joint, and in addition to the advantage of there being no opening between the post and rudder, it works much easier and steadier than by any of the other methods known.

In fitting the rudder to work into a hollow down the stern-post, so as to be quite close from top to bottom, or what is only necessary, from a little above the load-water mark to the keel or lower part of the rudder, so that there shall be no opening between it and the post, the after-part of the stern-post must be quite straight from top to bottom, and perfectly square across, but may be tapered to any convenient thickness the side way towards the lower end or keel. Thus, supposing the after-part of the stern-post and rudder-stock to be of an equal thickness of 12 inches from the top to the place of the wing-transom, and tapered from that to 8 inches at the keel, the hollowing out of the stern-post must be in the same proportion. Supposing the thickness 12 inches, take a piece of board of that length, and 6 inches in breadth, and cut it to the semicircle of 12; the central point at the edge of the board will represent the centre of the hinge or pintles of the rudder. Then, parallel to the straight edge of the board, or radius line, draw another straight line 1-3d of the radius without it, which last drawn line will cut off a segment, shewing how much must be cut out of the stern-post, which, according to the presently supposed thickness, would be four inches. In this case, the depth of the hollow must never exceed 1-3d the diameter of the revolving circle.

If you wish to leave the corners of the post a little stronger, the hollowing out may be reduced to 3-10ths of the diameter of the circle (about 3 and 9-16ths in this case), leaving half an inch thickness at the corners, which will be $2\frac{1}{2}$ inches before the centre of rotation, and the rounding of the fore part of the rudder-stock, by being continued $1\frac{1}{2}$ inches abaft the centre of motion, will leave 1-3d of the diameter of the circle between the after part of the stern-post, and the termination of the round on the rudder-stock,

which will allow a traverse of the rudder 38 degrees each way from the line of the keel prolonged.

From this it is evident that whatever portion of the circle is made to work in the stern-post, there must always be as much of the circle contained upon the rudder as to leave 1-3d of the diameter on each side when the rudder is in midships, clear of the after-part of the stern-post, to allow it to traverse to the assigned angle for steering. Thus, when the diameter is 12 inches, and 1-3d of it worked in the stern-post, the centre of the revolving circle is 2 inches abaft the extreme corners of the post, which would only allow the rudder to traverse 19 degrees on each side of the line of the keel; therefore the rounding on the fore edge of the rudder must be continued two inches farther aft, which will give 19 degrees more, making 38 degrees.

When there is only 3-10ths of the diameter working in the stern-post; the centre of the circle is then 2½ inches abaft the corners of the post, and will allow the rudder to go over 23 degrees on each side of the keel, supposing the fore part of the rudder rounded to a semicircle only; but if you round it 1½ inches farther on each side, it will then turn 15 degrees farther, making altogether 38 degrees as before.

At the termination of the circle on the side of a rudder 12 inches thick, there would be a check of about 1-4th of an inch deep, which if dressed aftwards would be almost imperceptible,—(*see Plate* VII. *Fig.* 128.)

Rudders made to work close into a circular hollow in the after-side of the stern-post may have the same kind of bands and braces as those done in the common way, by only making a small alteration in the form of the straps or braces at the shoulders, as shewn by *Fig.* 129, *Plate* VII.

Small vessels with rudders of this kind, and intended to have a neat appearance, may have the rudder hung with braces entirely, that is, both on the post and rudder, having a hole bored down through the centre of the rudder-post, and through all the braces, to the lowest, and an iron bolt put down through all, similar to the centre pin of any common hinge. By this method there is no necessity for any opening under the bands for shipping the rudder, for if there is sufficient room in the rudder case to enter the head up first, the rudder may then be put square too against the post, and the bolt reeved through all the braces, which will make the whole completely fast. For pink-sterned vessels, this method of fitting the rudder is particularly applicable. It may be done without having any straps or braces on the sides of the rudder or stern-post, by using what the shipwrights usually call gudgins, answering the same purpose as the braces. These are made with a strong eye, like the braces for the stern-post, but in place of legs or straps for embracing the sides of the post, they have a strong bolt projecting from the centre, with a strong square neck joining the eye, and driven firmly into the post.

In many parts it is the custom to have one of these gudgins drove through the top of the stern-post and after-beam, instead of a brace on the top of the post, for the uppermost rudder-band.

In concluding the subject of the rudder, a few remarks may be added, for the advantage of those whose practice has been limited, and who may have had but little opportunity of observing the various accidents to which this most important part of the vessel is frequently exposed.

1st, The uppermost rudder-band should not be placed very far below the place of the tiller, if that can be avoided.

2d, If it is a rudder with a round head working close in the counter, the rudder-head must be supported by means of a spindle fixed into it.

3d, The iron work for the rudder, and the whole materials and workmanship, should be of the very best; the lower brace should be longer and stronger than any of the others, and its straps of sufficient length to cross the post, and take two or three bolts in the dead-wood; the bolts should be put with a small angle, so as to be rivetted on rings in the opposite side; likewise the pintle for this brace should be the longest, and considerably stronger than the others. The straps must be of sufficient length to take hold of the aftermost piece of the rudder. It should also be very particularly fastened; for it is evident, that from the situation in which it is placed, it is not only exposed to the greatest strain in steering the vessel, but is also liable to a number of accidental jerks and heavy strains, such as by the vessel touching the ground in passing over a shoal, going in or out of harbours, or by grounding in rivers where the rudder may be exposed to damage, which perhaps cannot at the time be seen, or if so, repaired. In all these circumstances, it is certain that the lowest rudder-bands are exposed to the greatest strains, as they must sustain the first impulse of the pressure on the rudder, the other bands being at the same time little exposed; but if the lower bands are broke, the others have little chance of escaping, because the lower part of the rudder will then act with an additional leverage force to break the remaining bands. To the circumstance of the lower bands giving way unperceived, may be attributed many of those disasters which so frequently happen to ships at sea by the loss of their rudders.

4th, In order to prevent the rudder from being frequently unshipped, or otherwise damaged, when the vessel takes the ground, it should be kept 5 or 6 inches short of the lower edge of the keel at the fore part, and 9 or 10 inches at the after edge; also the bottom should be made a little sharp or rounding, like the bearding of the fore-edge, and the after-corner rounded up a little. The foot of the rudder being rounded in this manner, it will sink easier into the ground, or pass over a stone or hard substance, as the one or the other will slip easier to a side than if the rudder was flat on the bottom part. Also, when a vessel happens to strike the ground in passing over a bar or shoal, she does so commonly when the stern is descending; now, as she is going forward at the same time, she will make a drag or cut into the ground with her heel and rudder, tending very much to tear the rudder from the stern-post. Farther, although the lower end of the rudder should be a little higher than the bottom of the keel, and cut in the same level, its after-corner will nevertheless come in contact with the ground when the stern descends, and be struck with more violence than if cut with an elevation towards the after-part, and the corner properly rounded off.

5th, There should always be sufficient room left in the opening of the wood-locks for the rudder to lift as far as can be properly allowed on the length of the pintles. Also, the lower part or bottom of the keel should be left one and a half inches abaft the centre of the bands.

The pintles are always cast along with the braces or straps, but it has lately been proposed to cast them separately, so that upon any of the pintles breaking or bending with

any particular strain, a new one might be fastened into the brace with fore-locks, which would save the trouble of taking the braces off the rudder, and getting new ones cast.

Steering Apparatus.—First, the Tiller.—This a lever of wood or iron, as found most convenient; it is fixed at one end into the head of the rudder, and at the other end the power is applied for steering the vessel. Its length from the rudder-head should be about four times the breadth of the rudder; its thickness at the fore part of the mortise, the thwartship way, about 5-11ths, or one half the siding dimension of the rudder-head, and its depth at the same place one and a half times its breadth. In lining out this piece, it is generally kept about 3-4ths of an inch broader than the mortise the thwartship way at the rudder-head, and tapered from that to the end or tiller-head, to 1-3d of the breadth and depth added together. Thus suppose the breadth 5 inches, and depth 7 inches; then $5 + 7 = 12$, and 1-3d of 12 is 4 inches for the diameter of the head. The length of the tiller from the rudder-head to the end is divided into three equal parts; that next the rudder is left square; the middle division has the corners taken off in form of an octagon, and from that to the head is made round. The head is left about half an inch thicker, and paned up like a diamond, or carved to fancy.

It is found by experience, that a good steering vessel of 200 tons, having a rudder of 3 feet broad, and tiller of 12 feet (making a power of 4 to 1 with the extremity of the rudder), may be steered by one man without the assistance of any other power, when the weather is moderate. However, in strong winds the power must be increased. In vessels which have not a steering wheel, this is frequently done by fixing a block to the end of the tiller, and another at the rail or side of the ship; a rope is then rove through these blocks, one end being made fast at the rail, and the other held in the hands of the man steering; the power is thus doubled, being 8 to 1.

Various methods of increasing the power for steering are adopted. Most vessels under 300 tons are steered with the tiller and tiller-ropes, as above mentioned. Larger vessels are commonly steered by a power produced with the wheel and axle. The wheel is called *the Steering Wheel.* It is erected on the deck a little before the tiller. It is also sometimes fitted abaft the rudder-head, or where found most convenient. The wheel is made similar to any common coach-wheel, only having the addition of hand-knobs or spokes on the outside of the rim, to lay hold of by the hands in turning it round. The wheel stands vertically, being fixed on a horizontal iron spindle (it must be copper, if near the compass), on which is also fixed a drum or barrel. The wheels vary in dimensions from $3\frac{1}{2}$ to 5 feet in diameter over the extremity of the hand-knobs; the drum or barrel on which the tiller ropes are wound, is from 1-5th to 1-4th the extreme diameter of the wheel. The wheel-ropes are made fast to the end of the tiller, and pass through sheves or blocks fixed to the side rail of the vessel opposite the tiller-head, then to the barrel of the wheel, so that by turning the wheel either way, the tiller will move accordingly.

In the case of the tiller being of the common length, *i. e.* as long as to produce a power of three to one with the breadth of the rudder, the wheel rope is brought immediately from the tiller to the barrel of the wheel, having only the sheves or blocks at the rail to conduct the rope fair to the barrel. Suppose the breadth of the rudder of a ship of 300 tons to be $3\frac{1}{2}$ feet, the length of the tiller 11 feet, making, by the tiller alone, a power of 3 to 1; that the tiller-rope is taken to the barrel of a wheel whose power is 4 to 1; then a

power of 4 to 1, acting upon a power of 3 to 1, produces a total power of 12 to 1, as compared with the extreme breadth of the rudder; and with this, one man will be able to steer any common vessel of about this size. But for ships of 400 or 500 tons, the power must be made equal to about 18 or 20 to 1, to be steered in the same manner, with the common tiller and wheel, by one man only.

When the vessel is to be steered with a tiller abaft the rudder-head, which in this case must be very short (in many vessels it cannot be allowed longer than the breadth of the rudder), a great increase of power of the wheel, or by tackles from each side to the tiller and wheel, either by the one or other of these, or by both, is required. It is most frequently done by fixing a purchase of 2 or 3 to 1 on the end of the short tiller, and reducing the diameter of the barrel, to give the wheel more power over the barrel.

There are many other methods which might be employed for augmenting the power, as by wheels and pinions, &c. Whatever method may be employed, the power must always be adequate to steer the vessel by one or two men.

The wheel is considered to be of great advantage, not only in giving more power, but also in enabling the helmsman to steer the vessel nearer her true course. Mostly all vessels are fitted with steering wheels, even some of our one-masted vessels, such as smacks, have them, although it is considered to be a little more in the way of the main-sheet than the common tiller.

Channels.—The channels are a kind of projecting platform fixed to the side of the ship, for the purpose of giving the shrouds more spread than the bare breadth of the vessel, that they may the more powerfully support the side-strain of the masts. The channels, also, by projecting beyond the side, prevent the shrouds or lanyards from chafing or rubbing against the rails or upper works of the vessel. They are commonly made of 3, 4, or 5 inch plank, according to the size of the ship, and of sufficient breadth to keep the rigging clear of the rail, say 14, 16, 18, 20 inches, or two feet, according to the size of the vessel, and tumble-home of her top-sides. On smacks, in the Leith and London trade (vessels of about 180 or 200 tons register), the channels are commonly 7 or 8 inches thick, and from 10 to 12 in breadth; their length from one-half to 5-9ths of the ship's extreme breadth. The greatest spread of the rigging should not exceed one-half the ship's breadth, nor be closer than 4-9ths of the same. The dimensions of the channels for all kinds of smack or sloop-rigged vessels are made in a similar proportion.

The channels of ships of about 300 tons are generally about 4 inches thick at the inner edge next the ship's side, and thinned off to about 3 inches at their outer edge, or to the size of the moulding on the lower part of the sheer-plank on which they are often placed. Their length for brigs, and the main and fore masts in ships, requires to be about 2-3ds of the extreme breadth of the vessel, and fitted with a cant down at the outer edge of one inch to a foot of breadth. They are fastened to the side with 3-4th or 7-8th inch bolts, one every 2½ or 3 feet, these bolts being placed clear of the chains.

The Chains, by which the shrouds are attached to the side, consist generally of three links; the uppermost being very large, is rounded and made of iron, 3-16ths of an inch thicker than the other links; it embraces the dead-eye, and is called the strap of the dead-eye. When this link is pretty thick at the top part, the dead-eye is not so apt to

split with the strain. The link joining to this, at the under part of the channel, is long and narrow, and has its sides parallel to each other; it is called the middle link. The next link is made with a small bend the side way, so as to allow the lower end to lie flat against the ship's side when the upper one is in the direction of the middle link, pointing to the outer edge of the channel. The two sides of the lower link are set close together, at about 1-3d of its length from the lower end, where the opening is worked to a round of proper size to take in the chain-bolt, which is drove through it, and thus connects the chains and dead-eye to the ship's side. There is also a stout plate made to fit over the lower end of this link, with its upper and lower ends fitting close to the plank, so as to take a bolt in the lower edge of the next plank, below that in which the chain-bolt is driven; this plate is called the preventer-plate, and is of great service in keeping down the outer end of the chain-bolt, which also passes through the upper end of the preventer-plate.

All the chain-work should be made of the very best iron, as they are continually exposed to very heavy strains by the tightness of the shrouds which are attached to the dead-eyes. A certain strength of shrouds is required, and the chains should always be in proportion to them. If the chains have a diameter of 1-8th part of an inch for every inch of the circumference of the shrouds, they will be sufficiently strong.

(*Note.*—In proceeding with this part of the work, it will first be necessary to know the size of the shrouds; therefore see subsequent article on the strength of ropes and dimensions of the standing rigging.)

Thus, for a 6-inch shroud, the diameter of the chains will be 6-8ths or 3-4ths of an inch, which is sufficiently strong for the strength of the ropes; but when we consider that the iron corrodes and wastes, it will be safer to make them a little stronger than the above proportion. The chain-bolts should be made of the best iron, perfectly sound, and well hammered round at the neck, to prevent the rust from taking so much hold of them. Their diameter at the outer end should be about 1-5th of the circumference of the shrouds attached to them. They should be made with a taper from the middle to the point, which allows them to go easily through the timber, with less risk of splitting than when they are made parallel. They should always be a little thicker at the neck than in the middle, which gives more strength, and fills up the rimming of the plank.

It has been observed, that the chain-bolts should always be thicker than perhaps what is actually necessary to bear the strain of the shrouds; for although a smaller bolt than the common might be sufficient to hold till the shroud gave way, yet as the frequent, heavy, and inconstant strains to which they are subjected by the rolling of the vessel, added to the regular strain of the shrouds and their bearing on a small portion of the timber, wears or bruises the fibre of the wood on the upper side of the bolt at the outside of the plank, the bolt-hole becomes wide outside; the bolt is then less supported, soon grows loose and leaky at the lower side; consequently it is better to have them a little thicker at the neck than is barely sufficient for their strength, according to that of the shrouds.

The above proportions and observations may be considered as applying more particularly to square-rigged vessels, and therefore it is necessary to give the proportions,

and a few observations on those for one-masted vessels, such as smacks, cutters, &c. In the first place, it is evident, that in this rigg the weight of the masts, spars, ropes, and every thing therewith connected, is much greater in proportion than when the sails are supported by two or more masts, and having two sets of shrouds &c.; for, independent of the mast of smacks being so much higher, making the angle of the shrouds with it very small, it throws a greater strain on the shrouds to support it than if they were equally spread as a brig's shrouds. The leverage power of the sail is also increased; and having only half the number of shrouds, with half the angle of support, the strain on the shrouds of a smack is tripled in comparison to that on those for two-masted vessels. Now, the shrouds and chain-work connected with them must be in proportion to the strain to which they are subjected, and this being so mnch greater than for brigs, the former rules or proportions given will not answer both.

To illustrate the proportions requisite for smacks, or any vessels similarly rigged, I shall first state the dimensions of the shrouds and iron-works for a smack of 190 tons register.

A smack of 180 or 190 tons, has four 9-inch shrouds on a side.

Smacks have only chain-plates, instead of the linked chains as used in brigs, for connecting the dead-eyes to the side.

The chain-plates are made of strong plate or bar-iron, of about 3 or $3\frac{3}{4}$-inch iron in breadth, and about 3 feet in length, from the upper part of the channel downwards; they are about $1\frac{1}{2}$-inch thick, and tapered to 5-8ths of an inch thick at the lower end. Above the channel the breadth is worked to a round of about 2 inches in diameter, forming the hook, the point of which is turned inwards; it is also bent inwards close at the top of the channel, to stand with the inclination of the shrouds. The strap of the dead-eye is made of $1\frac{3}{8}$-inch iron; the crown of the hook of the chain-plate is $1\frac{3}{4}$ inch in diameter. The plate is bolted to the side with three $1\frac{3}{8}$-inch bolts.

Taking the above as a medium, the proportion of the chain-work of these vessels is as follows:—

1st, The size of the shrouds is found by the method pointed out in the article on the standing rigging. (*See next chapter.*)

2d, The diameter of the iron for the strap of the dead-eye is 10-8ths of an inch for every inch of girth of the shroud, calling the product eighth parts of an inch.

3d, The diameter of the back part of the crown of the hook of the chain-plate is 1-5th of the circumference of the shroud.

4th, The diameter of the chain-bolts, supposing three in each chain-plate, should be 9-8ths of an inch for every inch of the girth of the shroud, the product being considered eighth parts of an inch.

5th, The breadth of the plate should be twice the diameter of the hook, or about three times the diameter of the bolts.

6th, The thickness of the plate at the under side of the channel is 5-8ths of the diameter of the hook, or 1-3d of their breadth.

Dimensions of the Hasp for the Bowsprit.—This hasp is fastened to the inside of the stem or apron at one end, and to the hass-timber at the other. It is made of good iron, in breadth equal to 1-4th the diameter of the bowsprit; its thickness is from 1-4th to 1-5th of its breadth.

Main-sheet Horse or Hook.—The diameter of the iron in the round of the eye for the main-sheet strap, is 1-8th part of an inch for every 3 feet of the length of the main-boom, and fastened at each tale with three bolts drove through the main-sheet beam and stern-timbers.

Tackle Plates.—The diameter of the iron in the round of the eye of the tackle plates is 1-8th of an inch for every inch of the girth of the tackle pendant.

The Author has been favoured with the following dimensions of chain-work, and also the following table of the strength of hooks, by Mr. Alexander Thomson, foreman blacksmith in Mr. Scot's building-yard at Greenock. The table of hooks was taken from a number of experiments, and calculated by Mr. Matthew Muir.

Dimensions of Dead-eye Straps and Links for Merchant Vessels.

Tonnage - -	500	400	300	200	100
Dead-eye straps, in diameter,	$1\frac{3}{8}$ in.	$1\frac{6}{16}$ in.	$1\frac{1}{4}$ in.	$1\frac{3}{16}$ in.	$1\frac{1}{8}$ in.
Links to ditto ditto,	$1\frac{4}{16}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{16}$
Bolts to ditto ditto,	$1\frac{3}{8}$	$1\frac{6}{16}$	$1\frac{1}{4}$	$1\frac{3}{16}$	$1\frac{1}{8}$
Preventer-plates, in breadth,	3	$2\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{2}$

Preventer-bolts, the same as the chain-bolts.

The straps for hearts to the above ships are 1-4th inch larger in diameter than the dead-eye straps.

TABLE of the STRENGTH *of* HOOKS.

[Hooks made of round iron, width inside two diameters, will carry cwts. for the sum of the squares of the iron in eighth parts of an inch. Hooks made of the same iron, three diameters inside, will carry in the proportion of five to eight of hooks of two diameters.]

Diameter of Iron.	¾ Diameter of Iron.	1 Diameter of Iron.	1¼ Diameter of Iron.	1½ Diameter of Iron.	1¾ Diameter of Iron.	2 Diameters of Iron.	2¼ Diameters of Iron.	2½ Diameters of Iron.	2¾ Diameters of Iron.	3 Diameters of Iron.
Inches.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.
$\frac{1}{4}$	5.9	5.5	5.1	4.7	4.4	4	3.6	3.2	2.9	2.5
$\frac{3}{8}$	13.2	12.4	11.5	10.7	10.8	9	8.1	7.3	6.4	5.6
$\frac{1}{2}$	23.5	22.0	20.5	19.0	17.5	16	14.5	13.0	11.5	10.0
$\frac{5}{8}$	36.7	34.4	32.0	29.7	27.3	25	22.6	20.3	17.9	15.6
$\frac{3}{4}$	52.9	49.5	46.1	42.7	39.4	36	32.6	29.2	25.9	22.5
$\frac{7}{8}$	71.9	67.4	62.8	58.2	53.6	49	44.4	39.8	35.2	30.6
1	94.0	88.0	82.0	76.0	70.0	64	58.0	52.0	46.0	40.0
$1\frac{1}{8}$	118.9	111.4	103.8	96.2	81.6	81	73.4	65.8	58.2	50.5
$1\frac{1}{4}$	146.9	137.5	128.1	118.7	109.4	100	90.6	81.2	71.9	62.5
$1\frac{3}{8}$	177.7	166.4	155.0	143.7	132.3	121	109.6	89.3	86.9	75.6
$1\frac{1}{2}$	211.5	198.0	184.5	171.0	157.5	144	130.5	117.0	103.5	90.0
$1\frac{5}{8}$	248.2	232.4	216.5	200.7	184.8	169	153.1	137.3	121.5	105.6
$1\frac{3}{4}$	287.9	269.4	251.1	232.7	214.4	196	177.6	159.2	140.9	122.5
$1\frac{7}{8}$	331.7	310.4	289.0	261.7	264.3	225	204.1	182.8	161.9	140.6
2	376.0	352.0	328.0	304.0	280.0	256	232.0	208.0	184.0	160.0
$2\frac{1}{8}$	425.3	393.4	371.1	343.2	316.9	289	262.7	234.8	208.5	180.6
$2\frac{1}{4}$	475.9	445.5	415.1	384.7	354.4	324	293.6	263.2	232.9	202.5
$2\frac{3}{8}$	530.2	496.4	462.5	428.7	394.8	361	327.1	293.3	259.5	225.6
$2\frac{1}{2}$	587.5	550.0	512.5	475.0	437.5	400	362.5	325.0	287.5	250.0
$2\frac{5}{8}$	648.2	606.4	565.5	523.7	482.8	441	400.1	358.3	317.4	275.6
$2\frac{3}{4}$	710.9	665.5	620.1	574.7	529.4	484	438.6	393.2	348.8	302.5
$2\frac{7}{8}$	776.9	727.4	677.8	628.2	578.6	529	479.4	429.8	380.2	330.6
3	846.0	792.0	738.0	684.0	630.0	576	522.0	468.0	414.0	360.0

*Setting the Head.**—In building a vessel designed to have a head, the stem, from the lower part of the wales upwards, should be sided a little thicker than common, to give the head-knee or cut-water a broader base, and make it easier supported than when fitted against a thin stem. The knees and cheek-rails are principally intended to support the head; they should be good clean timber, neatly moulded to the proper sweep or curve, and projected forward with the exact sheer of the vessel. The cheek-knees and rails must be placed clear of the seams in the bow, for the conveniency of getting them caulked. The head should be first drawn on the plan of the vessel, and then laid down in the floor of the mould-loft, and moulds made to the same. The knees and rails are made with a regular taper from the bow to the back of the head or figure.

The dimensions of the knees and rails opposite the front of the stem are as follow :—

1*st,* The depth or moulding dimension of the upper rail is 5-8ths of an inch for every foot of its whole length, and regularly tapered or diminished from that to 2-3ds or 3-5ths of the depth at the stem.

2*d,* The thwartship or siding dimension is 3-4ths of the depth of the rail at every place throughout the whole length.

3*d,* The depth of the lower rail is 4-5ths of the upper one, and tapered off towards the fore end in the same manner.

4*th,* The cheek-knees are sided to shew the same depth as the upper rail, and tapered from the stem to the figure in the same proportion.

5*th,* The cross or vertical timbers are sided to the same size as the upper rail, at the places to which they are set.

With these proportions of the rails of the head, and a proper set of moulds, any good shipwright will execute this part of the work without farther directions.

Quarter Galleries.—The quarter-galleries on merchant ships, like their heads, is rather an ornamental appendage than a thing of any utility, particularly on small vessels. But on ships above 300 tons, they may be made for some useful purpose. When they are neatly finished, they contribute very considerably to the apparent beauty of the ship. Their extreme length, from the quarter-pieces forward, is generally 1-11th part of the length of the ship on the sheer-plank or gunwale, and depth or height about 2-3ds of the length. But this, of course, in all cases, must depend upon the depth of the quarters, as they must always be made to suit the upper works of the vessel. The framing part of the gallery of merchant vessels is generally composed of eight parts—four lying in a fore-and-aft direction, running perfectly fair with the sheer of the upper works of the vessel, and forming the side round out of the gallery—the others standing up and down between the windows. The principal piece of the framing is set vertically, but parallel to the rake of the stern, and projects as much out as the breadth of the gallery at the after end, forming a continuation of the stern, its outer edge being dressed to the same sweep, leaving sufficient wood and room for the mouldings, carved work, or whatever ornaments may be introduced into the design of the stern.

The upper and lower fore-and-aft pieces of the galleries are commonly called stools, and are made of 4-inch plank, fitted close to the side, bolted edge-ways to the same,

* For the proportions of the Head, &c. see p. 209, 212.

and made water-tight, the lower one serving as a floor to the gallery, and the upper one as the roof. The two middle pieces, commonly called the rims, are made of small compass timber, moulded to the side-round of the gallery, dressed to 4 or 5 inches square, according to the size of the vessel. Their outsides are bevelled to suit the form of the gallery the up and down way; a rabbet is taken out of the upper and lower side to receive the ends of the deals or planks for cleading in the gallery. The ends of these deals and seams are again covered by the mouldings, which project as far as the thickness of the architraves of the windows. The rims are bolted firmly to the ship's side at their fore ends, and let into and bolted firmly to the quarter-piece. The lower rim must be placed so as to run direct round from the moulding on the top of the arch-board, which moulding is mitred at the corner with that which runs along the gallery on the rim. All the fore-and-aft mouldings on the gallery must run well with the sheer of the upper works, and the upper rim range well with the carved moulding above the stern-windows.

The windows in the gallery, whether real or mock, must be set with the rake of the the stern; and all the heights of windows, mouldings, &c. forming an harmonious arrangement across the stern, and along the side of the gallery. If this is not attended to, the gallery will have a very awkward appearance when viewed on the quarter. (*See* the plans of the 400 or 500 ton ships, *Plate* XXIII. or XXIV.; also page 214.)

The rounding-out of the gallery at the after part is commonly done by bolting on large quarter-pieces, supporting them also by small knees against the side. The after ends of the stools or rims are let in and bolted to the quarter-pieces.

In large vessels, it is customary to allow the planking of the arch-board or upper counter to project as far over the main quarter-timber as the intended width of the gallery. Against the fore side of these planks, a piece of timber, moulded to the proper form of the gallery, corresponding to the sweep of the stern, is fitted; its upper and lower ends are secured to the main quarter-timber; it is also bolted in the middle to the planks and rails of the counter and stern, which are projected for that purpose.

There is commonly some ornamental or carved work on the quarter-pieces, corresponding with the finish of the stern. The cove part above the windows of the galleries, *i. e.* between the upper rim and the upper stool, is sometimes finished with shell-work; and round the edge, on the top of the stool, a neat ballustered rail is fitted, inside of which the life-buoy lies, ready to be flung to the assistance of any person who may be washed overboard. The part below the lower stool is also carved, or otherwise ornamented.

Coppering.—When a vessel is to be copper-sheathed, the bottom should be dressed very smooth, and all the projecting parts neatly rounded off. In several parts of Britain, it is the custom to plane the bottom, which takes off all the protuberances left by the roundness of the adze. This is an excellent plan, and makes the copper lie close to the plank, and have a very smooth surface.

Before commencing with the coppering, the ship should be all properly caulked, the seams paid over with pitch, and also all the rough pitch scraped off the edges of the seams, which are then to be filled up level with the surface of the plank. This is some-

times done by driving a thread of oakum in the mouth of the seam, but more frequently by nailing in a thread of spun yarn. After this, the bottom must be paid over with tar boiled with a little pitch to a gluey consistency, considerably softer than what is commonly used for paying the seams. The paper must now be prepared, by being dipt in the warm tar and pitch, and left to dry for a few days before it is used. The copper must also be pierced before it is brought to the ship, except what sheets may be required for the upper parts and ends of the vessel, which have to be cut suitable to the place where they are to be nailed on, and fillings up where square-sheets are not wanted.

The copper sheets are commonly about 4 feet long, and 13 or 14 inches in breadth, covering each about 4 feet of surface of the ship's bottom when nailed on. The thickness of the copper is denominated by the weight per square foot; the lightest used is 16 ounces per square foot, and running up to about 28, and sometimes to 32 ounces per square foot, which is the heaviest. The size for merchant vessels is commonly 24-ounce copper for the luff of the bow and bilges, and 18 or 20 ounces for the rest of the bottom, except a breadth or two along about the load-water mark at midships (which is apt to be rubbed by boats or fenders) which is put on of 24 or 28 ounce.

Sometimes the whole of the copper on the fore-body of the ship is 4 or 6 ounces heavier than that on the after-body, it being found to wear faster on the former than the latter part of the ship, by the reaction of the fluid when sailing. The piercing of the copper is commonly done by hand, with a short small-pointed punch made to the exact size of the nails, with a shoulder or stop to prevent it going too far through.

The place of the nails on the sheet is marked off with a chalk line after this manner: Strike a line all round the edges of the sheet, 5-8ths or 3-4ths of an inch within. Between the side-lines, divide the breadth into three or four equal parts; strike the chalk-line along the sheet on these divisions, thus making a line for two or three row of nails along the middle of the sheet. It is next divided the other way, by setting, from the line across the end, distances equal to what the lines along the sheet are apart; then strike lines across the sheet at these equal distances, which will divide it into squares of three or four inches, at the intersections of which the holes for the nails are to be punched; and on the line at the edge, and one end of the sheet, an additional hole between every cross-line, making the distances between them 1½ inch, which is the farthest they should be apart. All the middle holes are pierced one edge and one end, the other edge and end being pierced after the sheet is put on. This first sheet is called the pattern-sheet, all the others being done in the same manner.

Having the pattern-sheet thus lined out, lay a sheet upon a hard block of wood having an even smooth surface; place the pattern-sheet exactly over it, fasten them both to the block with two or three nails, then punch the lower sheet through the pattern; and thus you may continue punching, using the pattern-sheet for a considerable time until the holes in it appear to widen, when it will be necessary to change it, and use another for that purpose.

It must also be observed, that the copper punched through this pattern-sheet is only for one side of the vessel; and that required for the other side must have the end-holes in the opposite end of the sheets.

The paper and copper being thus prepared, the paper is put upon the vessel's bottom with small tacks or scupper nails. In commencing with the copper, it makes the most regular work to begin at the upper part of the bottom amidships, and work from that towards both ends of the ship, carrying the edge as fair as possible, and giving the after end of every sheet one inch of overlap over the fore end of the other, at the same time taking particular care that each sheet lie quite flat to the plank. In nailing, always begin in the middle of the sheet, and complete the two or three middle rows, beating the copper completely up before you commence nailing the edges, otherwise it will bag off between the nails.

When you approach towards the ends of the vessel, the sheets will begin to rise at their fore and after ends; therefore their upper edges must be gored or cut off to the proper height till such time as they are diminished to 1½ inch in breadth. When this first strake is completed, begin with the next under, placing the end of the beginning sheet right under the middle of the one above, and its upper edge, so as to cover one inch of the lower edge of the sheets above. When a number of sheets are tacked on, begin and nail them first in the middle; work them close up to the plank; punch the lower edge of the sheets above through the holes in the upper edge of the sheet below, and the fore end of the sheet abaft each; after they are all properly nailed, they must be beat perfectly smooth with a mallet. When you come to the stem, take care to ply the copper neatly into the hoods, not regarding how the edges of the sheets may appear to run, provided they are close fitted to the plank. When they are all nailed to the sides of the stem, its fore part, and two or three inches round each side, must be covered with sheet-lead of from 1-4th to 3-8ths of an inch thick, and properly fastened with copper nails a little stouter than those used for nailing the copper. Supposing several strakes got round, continue to work downwards till you come to the bilge, and then work from the keel upwards; fix the sheets first to the sides of the keel with a few nails, to keep them to their proper place; then work them neatly into the corner of the rabbet, and drive the nails close to it; ply the sheets close to the keel and bottom plank or garboard-strake; turn up the edges of the copper or lead which is under the keel, and nail it over the lower edge of the copper on the side of the keel; continue to work outwards towards the bilge, making the outer or upper edges overlap the under edges of the next succeeding strake right fore-and-aft. When you come near to the bilge-planks, where the size of the copper is altered, fill up the goring or narrow ends forward with the strong copper as well as that on the bilge amidships; but the gorings on the after-runs is the same size of copper as on the other parts of the bottom. In coppering the stern-post and rudder, if sheet copper is not put under the straps of the braces and pintles, you must be very careful to put it neatly round them, and set close to all their edges with a caulking-iron; the copper must also be nailed quite close to the back of the stern-post, otherwise it will soon be chafed off; also be very particular how you fit the copper into the end of the keel. The bottom sheet on it and the lower end of the rudder should be very strong copper. On the other parts of the rudder, the copper may be of the common thickness.

The Launching.—This operation is attended with more or less risk, according to the size of the ship, or situation of the place on which she is built. The principles on which it is performed are very generally known, so that any failure may be ascribed to some inattention or unskilful management in preparing the ways.

It is not intended to enter into any theoretical investigations of the pressure and friction of sliding bodies, as I have already noticed this subject, p. 23. I shall proceed at once to give some directions for constructing the ways, and launching, beginning first with launching from convenient places, *i. e.* under common or favourable circumstances, and afterwards offer a few observations on launching from particular situations.

It is supposed that the depth of water has been duly considered before the keel of the vessel is laid; also that the reader possesses a general idea of the mechanical principle employed in launching.

For the launching of any vessel, a considerable quantity of different kinds and descriptions of timber is required, for preparing the ground-ways, sliding-planks, bilge-ways, filling-up blocks, proppets, slices, shores, set wedges, &c.

The sliding-planks, which are the largest and longest pieces required, are in general made of fir logs, sometimes of elm, or whatever is found most convenient. In regular building yards, a set of sliding-planks and bilge-coads are constantly kept on hand, and often the lower ends of the sliding-planks are fixed stationary, being laid so far apart as to answer any vessel that is likely to be built on that launching place, the upper part being removed during the setting on and building of the vessel. The sliding-planks for the launch of small vessels not exceeding 250 or 300 tons may be made of fir logs of 12, 13, or 14 inches in breadth, and 6 or 7 inches in thickness; the bilge-ways about 12 or 14 inches square, and of a length between 2-3ds and 3-4ths of the length of the ship.

The usual way of preparing the sliding-planks is to first dress the upper side quite fair, and the outer edge straight and square to the face.

The side-ways, or ribbands, which are bolted to the outer edge of the sliding-plank, are about 4 inches thick, and of a sufficient breadth to bolt to the sliding-plank, and project up 4 or 5 inches above the same.

The upper edge, and inside of the plank for the ribband, is plained quite straight and smooth, and is then fastened to the sliding-plank with a number of stout bolts passing through it and the sliding-plank at distances of 3 or 4 feet between each. In order to give strength and security to the fastenings, the bolts are driven through a strong plate of iron, which stands up across the ribband, to prevent the upper edge from being split off by any side-pressure or strain. The bolts are clinched on rings on the inside of the sliding-planks. The vertical plates reach to within an inch or so of the upper edge of the ribband; they should have a small bolt, or stout nail, in each corner; but these must not be so long as to come through the ribband by one inch, lest they might interrupt the sliding of the bilge-coads.

When there are two or three lengths of logs used for the sliding-planks, or side-ribbands, their ends must not be butted square, but have a scarph of 10 or 14 inches in length, the lower end of the upper piece overlapping the upper end of the lower

piece in the direction of the launch. The butt of the ribband should make a shifting of 5 or 6 feet past the butt of the sliding-plank, and these should always be secured with bolts.

The side-ribbands may be left short of the fore end of the sliding-plank 4 or 6 feet, in order to give room for the dog-shore and trigger.

The bilge-ways are next to be dressed fair, planed smooth, and perfectly straight on the outer edge. They are frequently made of strong fir logs; sometimes by sawing a large log down the middle, and fixing an oak plank on the lower side as a sole, which is supposed to reduce the friction.

The sliding-planks for large vessels of 700 tons and upwards are made of two breadths of timber, bolted together edgeways, making up about 2 feet in breadth; and the bilge-coads are also large pieces of timber, or two pieces bolted together. In this case the side-ribbands are about 5 inches square; and a chock is taken out of the sliding-plank about one inch deep, into which they are fitted as tight as possible, and bolted down to the sliding-plank, in place of to the edge, as commonly done.

After the sliding-planks and bilge-ways are thus far prepared, and such blocks and other materials collected as may be thought needful, the next thing is to begin and lay the ways. Measure off their intended width between the ribbands, which for common merchant ships is about half the extreme breadth of the vessel; but for very sharp bottoms, the width of the sliding-plank should not exceed 3-8ths of the breadth. This point, however, must always be determined according to the form of the ship's bottom.

When the width is set off, running parallel to the keel, the height and declivity of the ways must next be considered, and a number of blocks laid for supporting the sliding-planks. These are laid at about 3 feet apart, pointing thwartships, the broadest and longest ones being laid next the ground, and bedded as solidly as possible. On the lower blocks a number of others are laid, making up the height to the under side of the sliding-planks. When the blocks are set, the sliding-planks are lifted on the top of them, and set exactly to the intended width and height with the proper declivity which the situation of the launch may require. When the ground is nearly level, and the vessel has a good way to run, it is necessary to lay the ways with as little descent as thought sufficient to cause her to slide freely, *i. e.* not to be less than half an inch to the foot; but this would be found too little were the ways laid perfectly straight the fore-and-aft way, as in this case the vessel would move very slow, and perhaps require some assistance; whereas, by laying them with a little round-up as you recede from their upper end, the declivity is continually increasing, by which, as soon as the vessel starts, her motion is accelerated.

The sliding-planks must be perfectly level the thwartship way, both sides of the ways of equal height, and out of winding with each other. When they are properly placed to their height, the blocks must be carefully made up to the lower side of the planks, observing to make them fit solidly upon each other, and bear equally through the whole breadth of the planks.

During the time of filling up the blocks, some of the shores should be set to the side-ribbands, and some thwartship pieces set across between the sliding-planks, to prevent them from shifting during the time of working.

When the ways are all completely stopped up to the proper height, it must be observed that they are lying completely fair and parallel to each other, and their side-shores set and secured; after which the sliding-planks must be set in a little at the upper ends, making the wideness between them about 3-4ths of an inch less at the ship's bow than at the stern, from which place they may be run parallel all the way to the lower ends. When the ways are thus completely set fair to their proper breadth, &c. all the side or spur-shores are placed with one end against the ribband on the sliding-plank, and the other sunk into the ground, with a broad shole drove down behind the heel of each, to prevent the ribband from being thrust out or split by the side pressure of the bilge-ways; also some shores or stretchers must be placed against the inside of the sliding-planks—all of which, and the sliding-planks or ways near the lower end, must be firmly piled down, to prevent them from floating up in the way of the high-water mark.

The ground-work and sliding-planks being thus laid and properly secured, the bilge-ways are then laid upon them, being taken aft till such time as they can be canted over the ribband clear of the bottom, and then hauled up inside the ribband to their proper place; after which all the space between the bilge-way and ship's bottom is fitted up hard with plank along the middle part; and towards the ends of the bilge-way, with thick pieces or slabs thinned away at the ends to suit the rising of the ship's bottom forward and aft. But when the bottom has much rising towards the ends of the bilge-coads or bilge-ways, the space is fitted up with short pieces of timber set on-end on the bilge-way, commonly called proppets. They are set on the bilge-way with a small inclination inwards, and secured from flying out by cleats nailed on the ship's bottom at the head of each proppet; also sometimes by a ribband nailed on the bottom, and another across all the proppets.

The bilge-ways being all stopped up, the wedges and slices for setting up the vessel placed and set hand-tight, the dog-shores must next be fitted; these should be made of oak, about 5 inches square and from 3 to 5 feet in length. They are fixed with one end against the side-ribband of the sliding-plank, and the other against a large cleat or piece of oak plank, fitted with coags, or natched and bolted into the outside of the upper end of the bilge-way.

The after-end of the dog-shores should be cut square, and the fore end with an angle or bevel of about 3 inches to a foot longer on the lower side. The cleat or stop on the bilge-coad must be placed so as to answer the dog-shore or trigger.

When every thing is thus far completed, all the filling-up pieces, such as chocks, slices, proppets, &c. fitted in, they must now be taken out again, in order to get the sliding-plank and bilge-ways greased. Before proceeding to take them out, be very particular, and have them all properly marked, so that they may be put in their respective places again when the ways are greased. When the filling-up pieces are taken out, the bilge-ways are launched aft, and canted off the ways upon three or four bearers, and served over with a thick coating of melted tallow; also the sliding-planks and inside of the side-ribband served over with the same. In the winter season, the tallow is often covered over with a coat of oil or soft soap. When this is done, the bilge-ways

are then canted on the sliding-planks, and hauled up to their proper place, and the dog-shore put up. Before filling up again between the bilge-way and the bottom, keep the bilge-ways half an inch clear of the side-ribband, by putting several thin pieces of wood between them, and setting a few shores between the bilge-way and the keel; likewise a thread of oakum laid along the seam, between the bilge-ways and the side-ribband, to prevent any dirt or chips from falling in between the side-ribband and bilge-coad.

When the bilge-ways are again completely filled up, a good stout shore must be placed between the keel and bilge-way, about 3 or 4 feet from the after end. After having overhauled and found that every thing is bearing fair, and that the slices or wedges are bearing equally through the whole breadth of the filling or setting up planks, you may then set the hands to harden up all the wedges and slices, &c. so as to bring a considerable portion of the ship's weight upon the ways. Get a stout rope made fast to the fore ends of the bilge-coads, and taken up over the vessel's bow, or through the outermost hawse-holes; bowse or haul these well tight, and make fast on deck; also with a strong spun yarn or small rope, nail all the small pieces of the filling up, proppets, slices, and wedges together, leaving a little slack between each; also the end of a rope, made fast to all the other heavy pieces of the launch that move with the vessel, must be taken on board. You may next see that all the blocks and shores are properly cleared. If the fore end of the keel hangs below the line of the sliding-planks, you must have the ground cut away to prevent the keel from coming in contact with it when passing over the quay or end of the ways. The after-block must now be cleared away, and a piece of wood or 4-inch plank set under the ship's heel, for a support during the time of taking out the after-blocks. This piece must be cut perfectly square the thwartship way, and set perpendicularly up under the after end of the keel, only having a very small inclination with its head aftwards, having its upper corner on the fore part rounded off, and its after corner on the lower end also rounded off, so that it may have no tendency to stop the first movement of the vessel, as it is left standing, and is overset when she starts. During this time the dog-shores and trigger must be properly secured, and if the sliding-planks have settled below their regular round-up, by the weight of the vessel, they must be raised up to the proper curve by driving some thin slices under them. Then proceed to harden all tightly up with as many hands as you have, so that the men shall be regularly distributed both inside and outside of the ways. When the vessel is thus brought to bear upon the ways, proceed next to take out the blocks from under the keel and down all the shores, beginning aft, taking them out, and clearing away forward the blocks and shores opposite them, to the foremost block, or such as you mean to launch with, which is generally the two foremost ones.

All things being thus ready, and the check cable or rope adjusted, and in many cases having a cadge anchor hanging over the bow, ready to drop when the vessel is fairly off the ways; lastly, take a look round the vessel, see that every thing is fair and clear, then knock out the triggers and strike down the dog-shores; and if the ship does not start immediately, the cap-pieces of the two fore blocks must be instantly split out,

by beginning at their fore side above, and their after part below, which will allow them to cant freely; but if the ways have little declivity, the help of a screw against the stem may be required. In knocking down the dog-shores, if the ways have much declivity, you should endeavour that they both fall at the same instant of time. For this purpose, the foreman or person who has the charge of the launch places two good hands, one at each dog-shore, and taking his station in front, when every thing is clear, he gives the word "down triggers," and instantly after, if all is right, the ship slowly begins to slide down the ways into the water. If the one dog-shore is knocked down before the other, the bilge-coad which is first free begins to slide away, leaving a very heavy strain upon the one on the other side, which jambs the dog-shore strongly, making it difficult to get down; and if it is not got down quickly, the vessel will be thrown off her parallelism, and ten chances to one but something gives way, the launch be completely destroyed, and more or less mischief done. But in order to avoid this as much as possible, and insure the falling of both triggers at the same instant, sometimes two heavy weights are suspended over pulleys at equal heights above the triggers, and the ropes of each joined into one, passing over a pulley at the front of the vessel, so that when every thing is ready, the rope is cut, and both weights falling on the triggers, they are knocked down at the same instant.

On Launching over Quays, or places where the water does not flow up to the level of the ends of the sliding-planks.—In this case the vessel must have a fall in launching, less or more, according to the height of the ends of the sliding-planks above the water. This fall cannot perhaps be avoided, yet its extent may be considerably diminished by laying the ways with a good declivity, and keeping them as low as possible at the outer ends. The force of falling will be increased or diminished in proportion to the height of the end of the ways above the water; and if the vessel is thin on the buttock, the farther she will descend; consequently a much greater depth of water is required to launch over a quay with a fall, in order to keep the vessel clear of the ground, than when launching from a proper slip. Also observe, that during a short space of time, when the vessel is equipoised over the ends of the ways, she may then be greatly strained. Such is the risk in launching large ships under these circumstances, that some have been so much strained in launching as to render them quite unserviceable before being thoroughly repaired. There is also considerable risk of the vessel going clear of the quay, because when her stern drops below the inclination of the ways, her bow, which is then within the quay, is topped up. and all the stoppings and proppets on the fore end of the bilge ways become loose, and if they are not properly fastened together, fall down. As the ship proceeds, and is about a fourth the length of the bilge-way of being clear of the ends of the sliding-planks, her bow being unsupported, she may fall down between the ways with her fore-foot upon the quay, which is sure of being damaged or carried away; and what is worse, there is great risk of the vessel being stopped in this dangerous situation.

In order to avoid as much as possible every difficulty in the way of launching, all the circumstances belonging to that operation must be duly considered when the building-slip is first made, and the keel of the vessel laid. A small difference of the declivity,

either of the keel or ways, will be of great consequence with respect to the safety of the launch. For let us suppose a vessel of 300 tons to be 96 feet in length, and to be launched stern foremost over a quay where the ends of the sliding-planks would be 2 feet above the water, and their height at about the middle of the vessel (as she stands on the blocks) level with the keel. When she had run 48 feet over the ends of the sliding-planks, her keel being supposed to have a declivity of half an inch to the foot, the after end would just be touching the water, and her stern begin to fall from the direction she was before, passing along upon the sliding-planks. If the velocity be not sufficient to carry her considerably farther out, and the water not sufficiently deep for this kind of launch, it is almost certain that the vessel would be stopped with her heel stuck into the ground, and her bow on the quay.

Again, suppose the keel to be laid with a declivity of one inch to the foot, and allowing it, at 2-5ths of its length from the stern-post, to be the same height as before, this will allow the ways to be laid with more declivity, by which the velocity of the vessel will be increased; likewise her heel will be immersed two feet in the water before she is topped off the end of the ways. In the first case, it would only touch the surface when half run off the ways; therefore, by laying the keel and ways with more declivity, bringing the stern two feet deeper in the water at the instant of the equipose of the ship on the ends of the ways, the fall will be decreased; and the velocity being increased, the vessel will advance much farther before her heel reach the same depth of water (even allowing the fall to be the same as before.) The risk in this case is much less than in former.

In the event of launching large vessels, built in situations where they are very apt to get strained, and receive great injury at the time they are in equipoise on the end of the ways, it will be necessary, previous to the launching, to have the vessel properly fortified in the inside, by placing two strong logs, as long as can be got within board, the one on the top of the other, two in each bilge, and their middles as near the centre of gravity of the vessel the length way as possible, and right above the bilge-ways outside. Let them be fitted solidly down to the ceiling, or by filling the under one upright, and to bear regularly all the length, but rather strongest in the middle. When this is done, shore them well down from the hold-beams, as far forward and aft as can be got; also fix shores all along the 'twixt-deck, to support the hold-beams. By this method of fortifying, the vessel will be very much stiffened, and greatly prevented from straining.

The sliding-planks in this case must be laid with as much descent as can rightly be obtained, leaving room for a strong bilge-way; and if there is an opportunity of getting them supported a small distance over the edge of the quay, it is so much the better. The sliding-planks should be rounded down at the outer ends, so that the bilge-ways may turn fair over them when the ship is falling down with her stern. There should also be a part of the outer edge of the quay taken down between the middle of the ways, making a kind of steep declivity for the fore end of the keel or stem, with its sides sloping outwards, covered with wood, and well greased; so that in the event of the vessel falling down with her bow before she is quite clear of the ways, her motion may not be retarded, but rather accelerated.

It must also be observed, that the lower or outer ends of the sliding-planks be equally supported, quite level across from the one to the other, and of equal length when horned from the centre-line of the launch. If this is not attended to, when the vessel falls down with her stern it will be in an angled direction, which, by throwing her off the direct line of motion, will overset all the stoppings and proppets on the fore ends of the bilge-ways, by which she will fall with a heel to one side upon the quay against her stem, or some part of the bow, which may receive considerable damage.

The bilge-ways (which should be about 3-4ths of the length of the keel) must be placed as far forward as the fore end of the keel or fore-foot, when the sliding-planks are to have little or no projection over the quay; but as it is very difficult to get proppets well secured so far forward, if the ways can be properly supported for a short distance without the building or quay, it is safest, and much surer of carrying the vessel clear, without the necessity of placing the bilge-ways so far forward under the vessel; same time, they should never be as much short of the fore end of the keel as what the sliding-planks are projected over the quay. In all situations where the vessel is exposed to a fall from the ends of the ways, the bilge-ways should be stopped up as far forward as possible.

When it happens that two or more lengths of timber are required to make up the whole length of the bilge-ways, the butt must not be near the middle of the ship or centre of gravity. One of the longest and best pieces must be placed in the middle, or so as to allow its after end to run 10 or 15 feet past the centre of gravity, and perhaps a piece at each end to make up the whole length. It is evident, that when the butt of the bilge-coad is near the middle, it not only deprives the vessel of the full support of the bilge-ways at a time when this is of the greatest importance (in canting or topping over the end of the ways), but may also be the means of stopping her in this most dangerous situation; for when the butt of the bilge-ways is at the centre of gravity of the ship's length, and she is equipoised on the ends of the ways, her whole weight is upon the butt of the bilge-coads. During the time her stern is descending, the other half of the bilge-ways goes clear out; the bottom is then bearing in an inclined position against the lower end of the fore half, which is still upon the sliding-planks, although it is entirely freed from the weight of the vessel, by her falling down aft and rising forward. There is then nothing to prevent the bilge-coad from falling off the sliding-plank, or flying forward by slding up from under the vessel's bottom, and of course her bow falling on the quay, from which she will receive considerable damage. When there is one length of bilge-coad, extending from 8 or 10 feet abaft the centre of gravity of the vessel to the fore end, it may be easily secured, for the stiffness of the bilge-way itself will be sufficient to carry the weight off the fore end; but as its fore end is loaded with the filling up pieces, proppets, &c. it is necessary to have a stout rope taken from the fore end over the bow of the ship, hove tight and made fast on deck; and thus by keeping every thing tight in its proper place, the vessel will run fair off from the end of the sliding-ways.

When three pieces are required to make up the length of the bilge-coads, the fore piece should be fixed to the end of the middle piece, with a flat scarph, with a stout

piece of plank nailed on each side of the scarph; also a long piece over the top of the scarph, as broad as the bilge-coad, to stiffen it in the way of the scarph, and prevent it from drawing end-ways. The dog-shore should, if possible, be placed against it. The after-piece of the bilge-coad may be simply butted to the after-end of the middle one with only a piece of plank nailed on one side, and over the butt, in the same manner.

After the filling-up pieces and proppets are all set, they must be cleated at the head, to prevent them from flying out; and where the bottom rises quickly, either at the bow or quarters, they will require two cleats at the head of each proppet, or one cleat at the fore or after edge, and a strong ribband nailed along their outsides to the bottom of the vessel. Sometimes it is necessary to have two ribbands nailed along the proppets and the cleats on the bottom fore-and-aft where it presents a very oblique surface to the bearing of the head of the proppets. The after-piece of the bilge-way in this case, by not being scarphed to the end of the middle piece, is at liberty to fly out from the vessel as soon as it is clear of the sliding-ways.

The fore pieces of the bilge-ways, as before observed, must be firmly connected together, and secured so that they may lift up with the bow of the vessel when she tops over the ends of the sliding-planks. This may be done by means of a rope attached to their fore end, and taken up over the bow, or by means of a chain to a ring-bolt fixed in the bow above water; they should also be steadied the side way by span pieces nailed to the bow.

On Launching Vessels in a transverse direction.—In the two former cases we considered the means of launching the vessel with her bow or stern to the water; but as they are sometimes built on the sides of narrow rivers or canals, where there is not sufficient room for launching in the longitudinal direction, they must be launched sideways, or, as commonly termed, broadside-on.

In preparing for launching in this case, the sliding-planks may be laid as in the common manner, only they must be kept so far apart, that the weight of the vessel may be equally distributed upon the sliders, whether two, three, or four sets of sliding-planks are used. If there are to be only two sliding-planks employed, which is sufficient for small vessels, the length of the ship about her load-water line must be divided into four equal parts, and the sliders placed at one-fourth from the bow and stern, leaving half the length of the vessel between them. When there are to be three sliding-planks, divide her length into six equal parts, place the two outside sliders 1-6th from each end, and the other in the middle between them. If four sliders are to be employed for a vessel of any considerable burthen, divide her into eight equal parts, place the two middle sliders each 1-8th part of the ship's length from the centre, and the two outside ones 1-8th part of the same from the bow and stern. In this kind of launch the side-ribbands must be very securely bolted, and well shored to the sliding-plank, because as the sliders under the vessel's bottom are shorter, and the sliding-planks farther apart than in the common launch, if the smallest difference in the greasing or height of the ways takes place, that slider which suffers the least friction will advance quicker than the other; and by throwing her off her true transverse position, subjects the side-ribbands of the sliding-planks to a very great and unequal degree of pressure or strain.

The sliders answering the same purpose in this case, as the bilge-coads or bilge-ways in the common case, require to be stout square pieces, equal in length to the breadth of the ship; they are put through under the keel, and the vessel blocked upon them by driving in a stout piece of plank under the keel, and a stout solid block on the upper side of the slider under the bilge, fastened to the slider by dogs, to prevent any chance of canting. When this is done, you block or shore up the other bilge in a similar manner. As the vessel will likely have a fall at the end of the ways, it will be proper to give her a small heel inwards by keeping the inside blocks a little slack, and shoring her well up at the side next the water, so as to make her fall more upright. The ways must be laid so far out, that she may fall clear of the quay or bank of the river.

Having considered the particular case of launching over quays, it may be observed that such situations should not be chosen for building on, if a more favourable and convenient place can be obtained, as the launch in this case is not only attended with more expense, but also with a greater degree of risk, than when the vessel is built in a proper slip, where she can be run fairly afloat from the ways.

In several places it is common to launch at low-water, when the vessel has to run over long flat sands; and the necessity for this is evidently, that the sliding-ways would, if left till the tide flowed, either be washed up, or covered over with sand by the surf. In this case the ways are laid as far out on the beach as there is sufficient water to float the vessel when the tide flows, the ways are laid with a small declivity, and the vessel is run off, bow or stern forward, at low-water, and rests at the end of the ways till the tide flows, when she is towed into the harbour.

When the ground over which the vessel has to run is uniformly hard, the whole process is very simple, and with a good number of hands, the ways may be laid, and a vessel of 200 tons launched in this manner with the greatest safety, excepting what danger may arise from an unfavourable change of the weather with the return of the tide. This kind of launch can only be depended upon for small vessels, large vessels being much more liable to get strained, and less manageable to get into dock or off the sands when the tide flows. When a vessel is to be launched over flat marshy ground, where some parts may be softer than others, the main object is to make solid beds for the blocks which support the sliding planks, to make the bearing as fair and uniform as possible.

I happened once to witness a very singular circumstance at the launching of a vessel of about 450 tons register. The vessel had a good way to run on, a very fair declivity of the ways, but the ground was soft and muddy. When she had advanced about half her length, the ground under the starboard bilge settled down. The motion being a little retarded, and the fore end of the bilge-coad falling into the hollow, caused her to cant, thereby raising her opposite side, and easing the weight off the proppets of the larboard quarter; the bilge-coads happened to be in three lengths, and the after-piece not being attached to the middle one, it separated, and with all the proppets standing on it, slid down the remaining part of the ways, keeping about 10 or 15 feet of start before the vessel. This sight was unlooked for, and had the ways settled on the larboard side at the same time, the ship would probably have forced herself off at the side of the ways, and the launch been thus completely destroyed.

Having mentioned such an accident as may happen from the unfair settling down of the ways, I shall offer a few observations on erecting them.

Launching over soft muddy ground.—The principal difference between this case and launching from regular made slips, consists chiefly in the greater nicety required in preparing the ground or bedding for supporting the ways, and in fixing the side-ribbands; for in place of bolting them to the outside of the sliding-planks, as commonly done, they are bolted on the inner edge of the bilge-ways, the inner edge of the sliding-planks being made perfectly straight and smooth. And observe, that by this method, when a great length of ways is necessary, a considerable saving of expense is effected, as no more side-ribbands are required than the length of the bilge-coad, and the ribband is much easier secured by a few cross-headed bolts driven through it and the bilge-coad, with a few shores from the keel to the side-ribbands; whereas, when they are put on the outer edge of the sliding-planks, they must extend the whole length of the ways, and of course be supported all the way with the side or spur shores, which is not only more expensive, but these spur-shores can be but little depended on for holding against any particular strain when placed in soft ground; and unless they are particularly well secured to the sliding-planks, the vessel may have a chance to burst them off and fall to one side of the ways. But when the side-ribbands are bolted to the inner edge of the bilge-ways, a few shores between them and the keel is all that is required, with only a few shores or piles to prevent the sliding-planks from being shifted during the course of the work; for if they are properly filled up, as the ship proceeds along her weight will set the sliding-planks and blocks so firmly together, that they will have little chance of moving or being shifted in the least. The advantages of this method have been proved by a long experience in several parts of the country where the situation is soft and muddy.

It now only remains to be observed, that before laying the blocks for supporting the two sliding planks, it is necessary to examine the ground in the direction the ways are to be laid, and if it is very soft, to cover it with 3 or 4 breadths of planks laid fore-and-aft ways, to form a foundation or base on which to erect the blocks. In laying these planks, some of the loose surface of the mud must be pared off, in order that they may lie perfectly flat and solid, laying a breadth or two more of the stiffest planks over the softest part of the mud. The planks must have their butts placed so as to make shiftings, so that no two planks shall have their butts at the same place. The lowermost blocks should be the longest, and to take in the whole breadth of the planks. If the weather and time is suitable for allowing these planks to lie for the course of two or three tides previous to launching, covered over with mud or any weighty material, to keep them from floating, they will become consolidated to the ground, and not so liable to settle down with the weight of the vessel when she is passing over them.

Improved Method of making the Sliding-Planks or Ways.—It has been mentioned that the sliding-planks are dressed and planed quite fair the length-way, and straight across on their upper sides, and straight and square on the outer edge, to which the side-ribbands are secured, projecting 4 or 5 inches above the sliding-planks; also that sometimes the ribbands are bolted on the inner edge of the sliding-baulks or bilge-coads,

and the inner edge of the sliding planks made straight and square. Now, although this last method is considered the best of the two, and both are found to answer the purpose, yet they are imperfect. From the principle on which they are constructed and commonly executed, should the ribband be split off at one side of the vessel, that on the sliding-plank at the other side has no tendency to prevent her from falling off the ways, unless the side-ribbands were put on at each side of the sliding-planks, which would be attended with much trouble and expense; to avoid which, and give more security to the launch, Mr. Adamson of Sunderland, a very able and experienced ship-builder, when preparing the launch, works a hollow or gutter in the upper side of the sliding plank, in form of a very flat semi-ellipse, making the depth in the middle 1¼ inch on 14 or 15 inches of breadth of the sliding planks. The hollow or gutter being made flat in the middle, and rounded up at the two sides, and the bilge-coads made with a corresponding round across their under sides, is the best possible form, and preferable to a circular hollow, by having less friction, and at the same time a greater lateral resistance to the side pressure of the bilge-ways. By this ingenious contrivance, not only is the launch better secured against accidents arising from the vessel falling off at one side of the ways, but also a very great saving in the expense of erecting them is effected, as no side-ribbands are required, and the hollow is very speedily taken out of the sliding-plank, which, when once prepared, may be laid aside, and answer for launching a great number of vessels; whereas, in the common way, the side-ribbands and spur-shores must be prepared for each. In all building yards, a set of ways and bilge-coads prepared in this manner, and kept for launching, would be found of great advantage. This Mr. A. finds to be the case, and the method is not only approved of by all who have seen it, but is also found to answer in practice.

On Launching Vessels whose Bottoms are coppered on the Stocks.—Ships are frequently built at places where there are no dry docks, nor even any convenient place for laying them on the ground, so as to get the cleats, which are nailed on the bottom for securing the heads of the proppets, &c. belonging to the bilge-ways taken off; in which circumstance, if the vessel is to be coppered, it must be done upon the stocks. In this case, you must attend strictly to the caulking. The whole bottom must be carefully examined and made perfectly tight, and the coppering completely finished, before preparing for launching; and lastly, the launch must be so contrived that every thing connected with the bilge-ways shall stand independent of any fastening or cleats to the vessel's bottom, which would destroy the copper. There are two or three ways by which this may be effected—as by binding the heads of the proppets by chains passing from the one side to the other, under the bottom, connecting them in such a manner that they can be easily disengaged when the vessel reaches the water, to allow all the launching material to be hauled from under the bottom. To do this properly, you must nail a stout piece of plank along the heads of the proppets outside and in; bore a few auger-holes through these planks; also have locking-pieces on the outside of the planks, and through these holes pass a chain doubled, so that the bight of the chains from either side may meet at the keel; put the double of the one chain up through the bight of the other from the opposite side; haul them tight, and put a bolt through the

bight of the chain, which is rove up through that of the other from the opposite side. The chains may then be set up tight, with wedges drove in betwixt the locking-pieces and the planks on the sides of the proppets. The bolt for locking or connecting the chains together should have an eye, and a rope taken from it on board the vessel either over the bow or stern, so that when she is fairly off the ways, the bolt may be pulled out between the bights of the chain, and the bilge-ways and proppets allowed to float out from under her bottom.

The proppets and bilge-coads may be also kept from flying out, by nailing a stout ribband along, to prevent them from flying forward or aft from the inclined surface of the bottom, and fixing 3 or 4 stout ring-bolts in the bilge-coads at the upper and lower end, the foremost one opposite the foremost proppet or so, and the aftermost one at the lower end of the bilge-ways, opposite the aftermost proppet. Put ring-bolts through the ship's bow and quarters above water-mark, right above those on the bilge-coads; the ring-bolts for the vessel's bow and quarters must have their heads made in form of a crook or dog-bolt for a windlass, the crook being about 1½ or 2 inches in length, and very strong at the neck; the rings must also be strong, and pretty large in diameter. When the bolts are driven in through and locked up properly on the ceiling, and the ring-bolts in the bilge-coads locked on the inside of the same, procure a few stout pieces of timber for wrung-staffs, of sufficient length to reach from the ring-bolt in the bilge-coad up through the ship's quarters; and having put one end into the ring at the bilge-coad, and the other up against that in the vessel, slip on the ring over it and the crook. Having secured three or four of these on each bow and quarter in the same manner, fasten a stout piece of timber on their inner sides, and opposite to the plank or ribband on the heads of the proppets; then between these set in short pieces of timber for shores, and wedge them all tight up, which will completely prevent the heads of the proppets fom flying out when they receive the weight of the vessel. The use of having the ring loose from the bolts, and to ship on the crook of the bolts through the vessel's side, is, that it may be easily unhooked, and allow the wrung-staffs to be disengaged. These rings must be fastened to the end of a small piece of cord, to prevent their being lost by falling into the water when they are tripped off the crook by the floating up of the vertical pieces, along with the bilge-coads, proppets, and other timber employed for the filling-up of the launch.

Lastly, the heads of the proppets may be secured from flying out, by first laying two or three short logs of timber thwartship-ways, with their ends under the vessel's keel, and the other projecting out over the top of the bilge-coad for 5 or 8 feet. From the outer end of these, diagonal shores may be placed against the ribband on the head of the proppets, which of course will completely prevent them from flying out by the pressure of the vessel.

CHAPTER II.

ON THE SIDE-PRESSURE OF THE SAILS AND THE PRINCIPLES OF MASTING, AND THE PROPORTION OF THE STANDING-RIGGING; ALSO ON THE WEIGHT OF ANCHORS.

In the first place, it will be necessary to shew the methods of finding the centre of gravity in the different forms of sails. To find the centre of gravity of a lugg-sail (*Plate* VII. *Fig*. 133), draw lines from the angular points, *i. e.* from the opposite corners, and the intersection of these lines is the centre of gravity.

2d, To find the centre of gravity of a jib-sail (*Fig*. 134), draw lines from the angular points to bisect their opposite sides, and the intersection of these lines is the centre of gravity of the sail.

3d, The top-sail is one which tapers towards the top, (*Plate* VII. *Fig*. 135). To find the height of its centre of gravity, erect a parallelogram, whose base is equal to the base of the sail, and its height to that of the sail; find the height of the centre of gravity of this parallelogram, and mark it on one side; draw a line from the hypothenuse of the largest right-angled triangle in the sail; find the centre of gravity of this triangle, and mark its height upon the side of the sail next to the side of the parallelogram on which you marked the height of its centre of gravity. Then to the difference of the height of these two marks, add 1-4th of the breadth of the base or bottom of the sail, that is, the base of the largest right-angled triangle; and with this distance in the compasses as a radius, and the height of the centre of gravity of the parallelogram as a centre, where it is marked on the edge of the same, describe an arc downwards, and out a little from the side of the parallelogram. Then, with the same radius and one point of the compasses, set in the hypothenuse of the right-angled triangle at the height of its centre of gravity, that is the point a'; describe another arc downward, cutting the former one at c; next, with the same radius and centre c, describe the arc $a\,a'$, and where this arc cuts the edge of the sail, draw a line across, parallel to the base or bottom of the sail, and it will pass through its centre of gravity; bisect the line drawn at that height, and it will be the centre of gravity of the sail, that is the point G, (*Fig* 135, otherwise *Fig*. 136, *Plate* VIII.) Divide the figure A B C D into two triangles by the right line A C; find their centres of gravity E and F as sepatate triangles; join these two centres by the right line E F, and it is evident that the common centre of gravity of these two, E and F, will be in some part of that line. In the same manner, as the common centre of gravity of two bolts fixed on the ends of an iron rod is in some part of that rod (*Fig*. 132, *Plate* VII.), according to the respective weights of the two balls; if they are equal in weight, their centre of gravity will be in the middle between them, but if the one is heavier than the other, it will be nearest the heavy ball. Therefore, in the case of the sail, which is divided by the right line A C into two triangles, A B C and A D C, and the centre of gravity of

each found, their common centre of gravity will be nearest the centre of gravity of the largest of the two triangles, which is A D C; and their common centre of gravity is easily found in the line E F, by drawing the diagonal B D, and then finding the centre of gravity of the triangle B C D (which is the point H), and the centre of gravity of the triangle B A D (*i. e.* the point I); and then joining these two points by the right line H I, the intersection of the line E F by the line H I is the centre of gravity of the whole sail A B C D.

Or when the two sides of the quadrilateral, as A B and D C (*Fig* 137, *Plate* VIII.) are parallel, the centre of gravity will be somewhere in the line L M, which joins the middle of A B and C D; it is also somewhere in the right line which joins the centre of gravity of the triangle B C D, and the centre of gravity of the triangle B D A; consequently it is in their intersection, *i. e.* the point G.

In like manner, the centre of gravity of any irregular figure may be found by dividing it into a number of triangles, and finding their centre of gravity respectively; then drawing lines from the centre of gravity of one to another, considering any two as a single body equal to their sum, concentred in their common centre of gravity. Draw a line from this new-found centre of gravity to the centre of gravity of any of the other triangles; find the common centre of gravity of these two, and so on, continuing till they are all reduced, and the last found centre will be the centre of gravity of the whole figure. The centre of gravity of any solid body may be found in the same way, if you have sections of that solid, and it be of equal density throughout. When the body is not homogeneous, the momentum of each triangle, section, or division, into which it is formed, must be found, and the whole reduced to one common centre of gravity.

Having shewn how the centre of gravity is found in any sail, we shall now proceed to consider the manner by which the power of the sails accumulates, according to their height upon the mast; but first notice, that the effective force of wind upon a square foot of surface, in feet per second, as found by Mr. Tredgold, is as follows:—

A gentle wind, ...	10 feet per second,	= .129	lbs. per square foot.
A brisk gale, ...	20 ,,	= .915	,,
A very brisk gale, ...	30 ,,	= 2.059	,,
A high wind, ...	50 ,,	= 5.718	,,
A very high wind, ...	70 ,,	= 11.207	,,
A storm, ...	80 ,,	= 14.658	,,
A great storm, ...	100 ,,	= 22.872	,,
A hurricane, ...	120 ,,	= 32.926	,,
A violent hurricane, to tear up trees, &c.	150 ,,	= 51.426	,,

Now, in order to proceed as simply as possible, let us first consider a sail of such a form as will admit a clear and simple demonstration, and require the fewest figures to express the momentum of its power, as a lug-sail, which is rectangular, being nearly of the same breadth from the bottom to the top. When hoisted, let its top be 64 feet from the surface of the water, and suppose its height to be divided into eight equal parts; let it be hoisted to the first division, which is 8 feet from the surface of the water. The top of the sail is fastened to the yard which is suspended across the

mast, and the lower end to the ship, or as low as the surface of the water, because every part of the ship above water is acted upon by the wind in the same manner as the sail, and has the same effect in pressing her over. Then, by taking the surface of the water as the centre of motion, the vessel can only be pressed over by the action of the wind on every part that is above that centre, the centre itself having no motion, because it has no space on which a power can act to produce it. At first the pressure must begin at nothing, and the first point or thread of canvas will give both place and power to action; so that, beginning at the centre, which is supposed nothing, the first point above it may be estimated at unity, or 1, and the next above that at 2, which is likewise double the distance from the centre, so that, whatever the power is that acts upon one, or the first space, the same power acting upon the second will produce double the effect, because it is double the distance from the centre. If mathematically considered, every point which exists between the centre of motion and the top will have its increase of power in proportion to the space between the centre and its place of action. Now it is certain that these points are as the powers they represent at their respective heights. Beginning at the centre, the first will present one single point,—the second will present two points, *i. e.* two in a vertical, and two in a horizontal direction,—the force of the third point will present three, and being placed at the third space from the centre of motion, will make three points each way; and as three points lying in one direction are supposed to form a right line, these six points, when placed in the direction of the forces they present, will form a right-angled triangle, whose opposite angles are 45 degrees, constituting the lower extremity of the triangle in *Fig.* 141, *Plate* VIII. The divisions of height are marked 1, 2, 3, 4, &c., and the powers are marked 1, 1, 1, 1, &c. In the right-hand triangle of each division is marked the accumulated force, expressed by the triangle in each division of the height, as 1, 3, 5, 7, 9, 11, &c. In the first vertical column are marked the squares of the divisions of the height, as 4, 9, 16, &c.; in the second, the half squares of the heights. This triangular figure represents the whole height and comparative pressure of the sail at every division of the height when it is a square or lug-sail. The first division shews the rise and form by which the powers are expressed. The similar triangles inscribed in the other divisions shew the accumulated force of all the other pressures at one view, collected in their respective stations. In the first division of height there is only one triangle—in the second, three—in the third, five—and so on.

Let us now lay down the dimensions of three differently formed sails, and illustrate, by way of example, their different advantages. Suppose them all of the same height, and to contain the same quantity of canvas. Let *Fig.* 138, *Plate* VIII. represent the lug-sail and its accumulated force geometrically expressed; *Fig.* 139 a sail whose perpendicular height and base are equal, and terminating in a point at the top, similar to a sloop's jib, and its accumulated force geometrically expressed; *Fig.* 140 a sail tapering towards the top, the breadth of the top being 3-5ths of the bottom, similar to a brig's square-sail, and its accumulated force geometrically expressed. The dotted lines produced above *Fig.* 140 represent the top-gallant sails, royal, &c. until the sail terminates in a point. Now, the height of these three sails (*Figs.* 138, 139, 140) is

supposed to be 64 feet from the surface of the water, and their breadth at top and bottom such as to present the same surface of canvas to the action of the wind. The lug-sail is 64 feet in height, and 32 feet broad; the jib 64 feet in height, and 64 feet in breadth at the bottom; the brig's square-sail is 64 in height, 40 feet broad at the bottom, and 24 feet at the top. Now, the advantages of these sails are exhibited by the situations of their centres of gravity, for their momenta of force is their surfaces multiplied by the height of their centres of gravity; and if we know these in each of the sails, it is only necessary to multiply the surfaces by the height of the centre of gravity, and we have the whole power of the sails respectively to press over the vessel. It is evident that the jib-sail is the best, for while it has an equal power to propel the vessel forward, it has at the same time but very little more than half the tendency to press her over. But in order to shew how the pressure accumulates as the heights, and how it is represented by a geometrical construction at all the different heights, let us proceed in the following manner to consider the power of the three sails laid down.

First, with the Lug-sail.—As this sail is of equal breadth throughout, each equal division of the height (of which there are eight) will contain an equal quantity of wind, which suppose to be blowing with a velocity between 20 and 30 feet per second; then the pressure of the wind being estimated at about 1.3 lb. per square foot, will give a pressure in each division of the sail of 4 cwt., and this multiplied by 8 will give the pressure of the wind on the whole sail at the given rate. Now, although the wind is acting with a force of 4 cwt. on each division, yet its effect will be increased in every division of height as they are farther from the centre of motion, as shewn by the triangular figure, where the powers are expressed by the number of the triangles in each division of the height. These triangles are also the number of times the centre of gravity in each division is removed from the centre of motion, where the power is supposed to commence, because the centre of gravity of each division is in its centre; these of course are increased in the same manner as the powers of the division itself. So that if it is required to find the impelling force of the wind on any sail, we have only to divide the height into any number of equal parts, and by taking the weight of each division and multiplying it by the number of triangles in its respective division of height, and adding these together, we find the impelling force of the wind in the whole sail.

Side-pressure of the Lug-Sail.

Power.	Height.	No. of Triangles.	Weight.	Effect.	Power.	Height.	No. of Triangles.	Weight.	Effect.
1 .	1 .	1 ×	4 =	4	1 .	5 .	9 ×	4 =	36
1 .	2 .	3 ×	4 =	12	1 .	6 .	11 ×	4 =	44
1 .	3 .	5 ×	4 =	20	1 .	7 .	13 ×	4 =	52
1 .	4 .	7 ×	4 =	28	1 .	8 .	15 ×	4 =	60

256 = the pressure or momentum of the powers. Otherwise, multiply the whole weight on the sail by the height of its centre of gravity, and the product will be the force of the sail to heel the vessel; that is, to multiply by the number of times the height of the centre of gravity of the first division is contained in the height of the centre of gravity of the whole sail.

Example.—The height of the centre of gravity of the whole sail is 32 feet; its height in the first division is 4 feet, which is 1-8th part of the height of the main centre of gravity; then if we multiply 32, calling that cwts., by 8, it will give 256 for the whole pressure; therefore 32 cwt. at the distance of 8 feet from the fulcrum of the lever would hold in equilibrium 256 cwt. at the distance of 1 foot.

The Sloop's Jibb, (*Fig.* 139, *Plate* VIII.)—This sail, containing the same surface as the former, will contain the same weight, *i.e.* 32 cwt.; but as it tapers with an angle of 45 degrees, the whole side-pressure will be reduced to little more than 2-3ds of the lug; and the geometrical expression of the pressure at the different heights will be in the form of a parabolic curve in place of a triangle. As this sail is 64 feet high, and 64 feet broad at the bottom, and terminating in a point at the top; when the height is divided into 8 equal parts, the middle division will be 32 feet, and the bottom 64 feet; the top is O; then, as the middle division is of the same breadth as the lug-sail, we may also estimate it at 4 cwt., and as the bottom is double the breadth, it must be estimated at 8 cwt.; so that by the tapering of the sail, each division of the height will be diminished 1 cwt.; therefore the centre of gravity of the first division will be reduced to half a cwt. Hence the number to be multiplied by the powers will be in the first division $7\frac{1}{2}$ cwt., in the second $6\frac{1}{2}$, in the third $5\frac{1}{2}$, in the fourth $4\frac{1}{2}$, &c.

Side-pressure of the Jib.

Power.	Height.	No. of Triangles.		Weight.		Effect.	Power.	Height.	No. of Triangles.		Weight.		Effect.
1 .	1 .	1	×	$7\frac{1}{2}$	=	$7\frac{1}{2}$	1 .	5 .	9	×	$3\frac{1}{2}$	=	$31\frac{1}{2}$
1 .	2 .	3	×	$6\frac{1}{2}$	=	$19\frac{1}{2}$	1 .	6 .	11	×	$2\frac{1}{2}$	=	$27\frac{1}{2}$
1 .	3 .	5	×	$5\frac{1}{2}$	=	$27\frac{1}{2}$	1 .	7 .	13	×	$1\frac{1}{2}$	=	$19\frac{1}{2}$
1 .	.	7	×	$4\frac{1}{2}$	=	$31\frac{1}{2}$	1 .	8 .	15	×	$\frac{1}{2}$	=	$7\frac{1}{2}$

172, the momentum or side-pressure. Or it may be found by the centre of gravity of the whole sail, as in the former example. The height of the centre of gravity of this sail is 21 feet 6 inches $= 5\frac{1}{3}$ divisions; therefore 32 cwt., the weight of the wind on the sail $\times 5\frac{1}{3} = 170$ cwt. 8 qrs., which amounts to nearly the same; but if we multiply by 21 feet 6 inches, and divide by 4, the product is correct.

Example.—32×21 ft. 6 in. $= 688 \div 4 = 172$ cwt.; and this weight at 4 feet from the centre will balance 32 cwt. at 21 feet 6 inches from the same.

Now, if we take the product of each division $7\frac{1}{2}$, $19\frac{1}{2}$, $27\frac{1}{2}$, &c. from the scale on which the sails are drawn, and mark them from the vertical line on the centre of each division of the height, the points will be in the line of the parabola, which shews a geometrical expression of the whole accumulated force of the sail according to its form, and the measure of force at the respective heights.

The Brig's Square-sail or Topsail, (*Fig.* 340.)—This sail is likewise of the same size and height, and will be acted upon by the same quantity of wind, *i. e.* 32 cwt.; but from its being of a different form from the others, the momentum of its powers will be different. Its height is 64 feet, breadth at the bottom 40 feet, and at top 24 feet; then as the height is supposed to be divided into 8 equal parts, the bottom division will represent 5 cwt., the middle 4, and the top 3; so that from the breadth at the top being

diminished equal to 2 cwt., the top of each division will be $\frac{1}{4}$ cwt. less than the one immediately under; therefore the centre of the first division will be diminished 1-8th, and the next 3-8ths. Hence the weight to be multiplied by the ratio will be $4\frac{7}{8}$ cwt. in the first, $4\frac{5}{8}$ in the second, $4\frac{3}{8}$ in the third, $4\frac{1}{8}$ in the fourth, $3\frac{7}{8}$ in the fifth, &c.

Side-pressure of the Topsail.

Power.	Height.	No. of Triangles.		Weight.		Effect.	Power.	Height.	No. of Triangles.		Weight.		Effect.
1	1	1	×	4.7	=	4.7	1	5	9	×	3.7	=	34.7
1	2	3	×	4.5	=	13.7	1	6	11	×	3.5	=	39.7
1	3	5	×	4.3	=	21.7	1	7	13	×	3.3	=	43.7
1	4	7	×	4.1	=	28.7	1	8	15	×	3.1	=	46.7
											32 cwt.		235.0,

the momentum of the powers or side-pressure. Or by the height of the centre of gravity, which is 29 feet $4\frac{1}{2}$ inches, multiplied by the weight 32 cwt. = 235 cwt. = 11 tons 15 cwt.

By this method of computing the side-pressure of the sails, we obtain at once a clear view of the effects produced by the three different sails, each spreading 336 yds. of canvas.

The momentum of the lug-sail is 256 cwt.; hence it would require a weight equal to 64 cwt. at 4 feet from the centre of the ship, to balance the side-pressure of the sail, and keep her upright.

The momentum of the jib (*Fig.* 139) is 172 cwt., and would require a weight equal to 43 cwt. at 4 feet from the centre of the ship to balance the side-pressure, and keep her upright.

The momentum of the brig's topsail (*Fig.* 140) is 235 cwt., and would take a weight of 50 cwt. nearly, at 4 feet from the centre, to keep her upright. It will be observed that the sloop's jib only requires about 2-3ds of this weight to counterbalance its pressure.

By this method of investigating the action of the wind and the pressure of the different shaped sails, it appears that the jib (*Fig.* 139) has an important advantage over the others on account of the side-pressure being so much diminished; and did not the whole weight and action of the sail bear to leeward of the centre of the ship, the effect produced would be found the very same as the result of the above calculations.

The above method of laying down a geometrical expression of the powers of the sails may still be farther explained. Thus the height is divided into 8 equal parts, but may be divided into any number, as 4, 6, 8, 10, &c.; so that each part may contain equal quantities, as 4, 8, or 10 feet. And when the sail is tapering, estimate the middle division at 2 or 4 feet, but not to exceed half the number of feet in any division or number of divisions of the height. Thus supposing the weight or force of the wind in the middle division to be 5 cwt., we may call that division 5, and the product will be cwts. and parts; or supposing it to be 200 lbs., it may be called 4, and the result will be in 50 lbs.; also if the weight be 60 lbs., it may be called 3, and the result will be in 20 lbs.; and so on.

When the middle division of the height is at half the number of the whole, or of the feet in one division, the figure of the powers will be in the most suitable proportion, and most easily described. There is also less work in the operation than when large numbers are employed.

If the weights are estimated in cwts., the ordinates of the figure will be expressed in

feet for cwts. If expressed by 20 lbs., they will be feet for 20 lbs.; and the neat weight may then be found by reducing them to any regular standards, such as tons, cwts., &c.

The dotted lines and curve continued above (*Fig.* 140), shew the effect produced by a continuation of the sail with the same taper to the top. The figures marked on the left of the centre, as 1, 2, 3, 4, 5, &c. are the ratio of the powers; and those on the dotted line in the centres of the divisions of height are the estimated weight of the divisions in cwts. qrs. &c.; and the figures on the right of the curve of expression are the products, feet for weight and weight for feet, feet for cwts. or cwts. for feet; so that by adding these we have the whole pressure in cwts.

Although (as observed at first) the method of multiplying the weight in the divisions by the ratio of the powers, or the whole weight by the height of the centre of gravity of the sail, is the easiest method of finding the power of the side-pressure, yet I have thought it proper to lay before the reader a full and interesting demonstration for the side-pressure of the sails, exhibiting at one view how much the vessel is relieved by reefing, lowering, and diminishing the sail, and how much she is oppressed by hoisting up or setting higher sails on the masts. Although this process is not considered absolutely necessary for the practical seaman, with respect to his knowledge of carrying sail on the ship, yet it will be of advantage to those who are not sufficiently experienced, and who may be engaged in the fit-out of vessels; for by seeing clearly into the first principles, they will be better able to manage with advantage their important business, and have less chance of falling into extremes, which are not only unprofitable, but dangerous in their effects.

The foregoing explanation is no doubt sufficient to enable any person acquainted with the principles of mechanics to calculate the ultimate pressure of the sails of any vessel, which resolves itself simply into finding the centre of gravity of the whole sails, (which point is call the *centre of effort*), and multiplying its height above the surface of the water, supposed to be the centre of motion, by the weight or power of the wind, according to any given velocity.

Calculation for the Centre of Effort of the Sails of a Smack of 173 *tons measurement.* (*See Rigging-plan,* Plate XXV.)

	Area in Feet.	Height of Centre of Gravity.	Momenta.		Area in Feet.	Dist. of Cent. of Grav. from Perpendic. at Stern.	Momenta.
Mainsail,......	2540	× 35	= 88900	Mainsail......	2540	× 36.5	= 92710
Gaff-topsail...	854.5	× 76	= 64942.5	Gaff-topsail...	854.5	× 51	= 43579.5
Foresail........	487.5	× 25.5	= 12431.25	Foresail.......	487.5	× 74.5	= 36318.75
Jib.............	741	× 26	= 19266	Jib............	741	× 98	= 72618
Jib-topsail.....	644	× 56	= 36064	Jib-topsail....	644	× 90	= 57960
Sum of areas =	5267		221603.3	Areas =	5267		303186.25

221603 5267 = 42 feet, the height of the centre of effort.

And 303186 ÷ 5267 = 57.5 feet, its distance from the perpendicular at the after side of the mainsail; consequently, if a perpendicular be drawn at this distance forward from the vertical line at the after corner of the mainsail, and also a horizontal line at

42 feet up from the surface of the water, they will intersect each other in the centre of effort, as marked on the plan, (*Plate* XXV.)

By the same processes, it is found, for the schooner (*Plate* XXVI.), that the centre of effort (as marked on the plan), from the after corner of the mainsail, is 52 feet 11 inches, and its height above the surface of the water $37\frac{1}{2}$ feet, when the whole sails are set. In the same manner is the centre of effort found on the rigging-plan of the ship (*Plate* XXVII.)

Proportions and Dimensions of Masts, Yards, Booms, &c. for the various Classes of Merchant-Vessels.

The just proportioning of the masts and sails is an object of the very utmost importance, insomuch that, however beautiful may be the shape of the hull for fast sailing, yet if the masts and sails are not duly proportioned, the sailing and other movements of the vessel will fall short of what might otherwise be expected. Lest any doubt on this point should arise from a knowledge of the great diversity in the dimensions of the masts, rigging, and shape of the sails of vessels of different nations, let it be remembered, that each is adapted to the construction of the vessel to which they are applied.

There is a particular proportion for the masts, and shape for the sails, of each distinct class of shipping, found to answer best. Although vessels of the same rigg may be found to differ a little in their general dimensions, and each to answer their sailing movements, yet, if these dimensions differ materially, and their construction become dissimilar, the same form and dimensions of sails, masts, and yards, will not answer both, so as to be equally convenient and effective. Hence the necessity of employing two or three masts, and of giving the sails a particular form, agreeable to the magnitude and construction of the vessel.

If a ship were always exposed to the action of some unvarying force, or the action of uniform winds and waves, and always loaded to the best advantage, we might be able to deduce, by mathematical investigation, the best form and dimensions of the sails for every description of vessels; but as these requisite conditions do not exist, it is only actual trial, experience, and observations on the behaviour of ships at sea, that can supply the desideratum. However, from a mathematical method of digesting these observations, we are enabled to draw the most reasonable conclusions, for finding the proportions of the masts and sails for the different classes of shipping.

The first thing to be known previous to proportioning the masts and sails of any vessel is her ultimate stability; and as it is only experience and a comparison of the stability of other vessels of a similar construction that can discover this to the requisite degree of exactness, the rules which we lay down must be founded on a knowledge of the dimensions of the masts and spars of such vessels as are well proportioned and rigged, and have been found to answer their steering and sailing movements.

It has been shewn that the stability or side-stiffness of all common constructed vessels is—1*st*, As the squares of the breadth; 2*d*, Singly as the length; 3*d*, Singly as

the depth. The side-pressure of the sails, or their power to heel or cant the vessel over, according to their height and dimensions and particular form, is simply as the breadth, and as the squares of the height of the sail. From this mathematical view of the principles by which the masts and sails should be made proportional to the ship, it appears that the height of the sails should be proportioned by the breadth of the ship, and the breadth of the sails by the length of the ship. However, there are certain circumstances which preclude acting entirely on this principle.

The method of finding the length of the masts by the breadth of the ship alone, which is the general practice, would be found sufficiently correct, were the length, breadth, and depth of all vessels in the same proportion; but we find that this is not the case, and know that the sails cannot, in many instances, be made in proportion to the length of the ship. In long, narrow vessels, if the length of the masts (which regulates the height of the sails) are in proportion to their breadth alone, before a sufficient quantity of canvas can be spread, the sails become too broad to stand well by the wind; also the stay-sails lie with too flat an angle, by which their propelling power is considerably diminished, and these sails in particular require to be set to a certain height to produce their greatest effort.

Two vessels may be of the same breadth, and yet the one 6 or 8 feet longer than the other; the stability of the long one will be 1-6th or 1-8th greater than the other, the capacity being that much more. Now we find, that by proportioning their masts by their breadth alone, there would be no difference in their lengths, and also that the breadth of the sails cannot be made proportional to the additional stability of the long ship over the other. That they may stand well by the wind (by increasing the surface of the sails, without adding to their height, the yards become long and unhandy), it becomes necessary that a sufficient quantity of canvas be spread, by giving the sails more hoist than would be indicated by proportioning the length of the masts by the breadth of the ship only. There is therefore a necessity of taking in a certain portion of the length of the ship, as well as the breadth, to find the length of the masts. The principle on which the following rules for the length of masts are founded, is the taking a proportion of the length of the ship, and disposing it in such a manner that the masts will vary in their lengths, agreeable to a mean proportional of ships of the same breadth, but differing in length to the extent observed in the general construction of merchant ships; and it is hoped that these rules will be found worthy of attention, as they will produce a medium dimension strictly consistent with well tried experience.

On the Proportions of the Masts, Yards, &c. for a Ship.

1*st*, *To find the Length of the Main-mast.—Rule.* To three times the breadth of the beam per register, add one-third of the length of the load-water line, including the breadth of the main stem and stern-post, and 4-7ths of the sum is the length of the main-mast.

2*d*, *The Length of the Mast-heads,* from the lower part of the trestletrees to the top, is 5 inches for every three feet of the whole length of the mast; or—*Rule,* multiply the full length of the mast by .14 for the length of the head.

3d, To find its Diameter.—Rule 1st, Make the diameter at the partners of the main-deck, for Riga timber, 1 inch for every $3\frac{1}{2}$ feet of the full length of the mast. *Rule 2d,* Make the diameter at the partners 2-7ths of the length of the mast, taking inches for feet. *Rule 3d,* Multiply the ship's extreme breadth, feet and inches, by .68; cut off the decimal, which multiply by 8 for the diameter in eighth parts of an inch. *Rule 4th,* For American yellow pine mast, multiply the ship's extreme breadth by .72 for the diameter at the partners.

Another method for finding the length of the main-mast, either for brigs or ships, which I have found to be very correct in almost every case, is as follows:—

For a Ship's Main-mast.—To one-third the length of the load-water line, including the main-stem or stern-post, add three times the breadth of the midship-frame, exclusive of the plank and the housing of the mast from the main-deck to the kelson, and half that sum will be the length of the main-mast in feet and inches. To find the diameter, multiplying the length by .3 gives the diameter for American pine; or 2-7ths of the length, taking inches for feet, gives the diameter for Riga timber; or, what is the same, make the diameter 1 inch for every $3\frac{1}{2}$ feet of its length.*

4th, For the Diameter at the Top.—Rule. Make the diameter at the top 2-3ds of the diameter at the partners. When the mast is to this size at the top, and lined to the regular sweep, you have the diameter at the hounds, at which place it is left square and finished off with the cheeks.

5th, Size of the Trestletrees is 7-8ths of the diameter at the partners, at least not less than 3-4ths of the same.

6th, For the Main Top-mast.—Rule. Make the length of the main top-mast 4-7ths of the length of the main-mast.

7th, Diameter of main top-mast at the cape, 1 inch for every three feet of the full length.

8th, Do. the size of ditto at the top, 2-3ds of the diameter at the cape.

9th, For the Main Top-gallant Mast.—Rule. Make the length of the main top-gallant mast 5-9ths of the main top-mast, and its diameter 1 inch for every yard of its length.

10th, The Length of the Main Royal-mast, from heel to pole, is 4-7ths of the main top-gallant mast, and its diameter 5-8ths of the main top-gallant mast. *11th,* Length of the pole is 3-5ths of the length of the mast from heel to the rigging; diameter at the same 2-3ds of that at the cap; at the truck, 3-5ths of the diameter at the rigging.

12th, For the Fore-mast.—Rule. Make the length of the fore-mast 14-15ths of the main-mast, and its main and other diameters in the same proportions as the main-mast.

13th, Fore-top and Top-gallant Masts.—Rule. These masts are generally 19-20ths of the length of the main-top and top-gallant masts, and their diameters in the same proportion.

* The reader is requested to contrast the above rule with the following for a brig's main-mast. To 1-3d the length of the ship at the load-water line, including the main-stem and stern-post, add three times the extreme breadth per register, also the depth of the hold from the upper part of the main-deck to the top of the floor-timber, and half that sum will be the length of the main-mast in feet and inches. The diameters are found as for a ship.

14th, To find the length of the Bowsprit without the Knightheads.—Rule. To 1-3d the length of the load-water line, add the ship's extreme breadth, and half this sum will be the length of the bowsprit without board.

15th, The Diameter of the Bowsprit at the Stem-head is equal to the diameter of the main-mast at the partners.

16th, And its diameter at the outer end 2-3ds of the diameter at the stem.

17th, The Cleats left on for the heart of the Fore-stay are 4-7ths of the length from the knight-heads, or 3-7ths of the length of the bowsprit set in from the outer end.

18th, The Jib-boom. The length of the jib-boom is 1¼th the length of the bowsprit without the knight-heads; its diameter at the cap 1 inch for every three feet of its length; the diameter at the outer end 2-3ds of the diameter at the cap.

19th, For the Mizen-mast—The length of the mizen-mast (when set on the same level as the main-mast*) is 9-10ths of the length of the main-mast, and its diameter at the partners 3-4ths of the diameter of the main-mast at the same.

20th, The length of the Mizen-topmast, Top-gallant, and Royal-masts, are 3-4ths of the length of the main-topmast, main-top and gallant, and main royal-masts, and their diameters in the same proportions.

21st, Mizen-boom and Gaff.—The length of the boom may be found by multiplying the ship's breadth by 1.2; or make it such as to be 1-3d of its length over the taffrail. Its greatest diameter should be at 1-3d of its length from the end; but if the sheet is within that distance, it must nevertheless have its greatest diameter at the sheet, which should be 1 inch for every 3½ or 4 feet of its full length; or if we multiply its length in feet and inches by .23, the product is the diameter at the sheet in inches and parts. Its diameter at the mast or cheeks is 2-3ds of the diameter at the sheet; and its diameter at the outer end is 3-5ths of the diameter at the sheet. It is lined with a rounding-sweep, the same as a yard, having its greatest diameter at 2-3ds of its length from the mast.

The Gaff may be made about 2-3ds the length of the boom, and ought to have its greatest diameter at the tail of the cheeks, or at 1-7th of its length from the mast. The diameter at this place is one inch for every 4 feet 4 inches of its length; or for the main diameter—*Rule,* multiply the length by .24 for the diameter in inches and eighth parts. The outer end is half the main diameter, and is lined with a rounding-sweep, the same as the boom.

22d, Of the Tops, &c.—The breadth of the main-top is half the extreme breadth of the ship, adding the diameter of the mast; or. *2d,* make the breadth of the top 5-9ths of the extreme breadth of the ship.

The depth of the Trestletrees is 5-6ths of the diameter of the mast at the top of the cheeks, and their thickness 3-7ths of their depth. Their length 5½ or 6 times the diameter of the mast; or, *2d,* their length half the breadth of the top.

The Crosstrees are in length equal to the breadth of the top; their siding dimension equal to half the diameter of the topmast at the cape, their depth 5-6ths of their breadth.

* When the step of the mizen-mast is higher than that of the main-mast, such additional height must be deducted from the length of the mizen-mast, as given by the above rule.

The length of the Cap is 3½ times the diameter of the mast-head; their breadth 1 and 3-4ths the diameter of the topmast; their depth from 3-4ths to 7-9ths the diameter of the topmasts, which pass up through them.

23d, *The Topmast Trestletrees* are half the length of the main trestletrees, and bear the same proportion to the topmasts as the main trestletrees to the main-mast.

24th, *The Topmast Crosstrees* are half the length of the main-crosstrees, and in the same proportion of thickness.

The Cap of the Topmast is in the same proportion to the top-gallant mast as the lower cap is to the topmast. Thus all the tops, caps, and crosstrees are made in proportion to the masts or jib-booms they have to support.

On the Proportions and Dimensions of the Yards.

There is a little variation in the lengths of the yards of ships of nearly the same dimension, according to the particular rigg or trade for which they are adapted.

Ships employed in the foreign trade have commonly longer yards than those of the same size that are employed in the coal and coasting trade; yet both have their particular advantages, being properly adapted to the build of the vessels, and the trade in which they are employed.

Vessels in the coal and coasting trade are generally of a broader and lower construction than those in the foreign trade, on account that a greater stability is required, these having often to perform one half their passages in a ballast-trim; also, as they are more frequently beating to windward in narrow channels, in which case narrow sails are found to answer best, as the ship will lie closer to the wind, and sail faster, than with the same quantity of canvas in a broader sail, when laid with the same angle to the wind; also the yards being shorter, are lighter and easier braced round, which is a great advantage in navigating narrow channels.

Ships for the foreign service are commonly built deeper in the hold, to give room for some particular stowage, and in general they have less stability than coasting vessels of the same size; therefore their masts are rather shorter, and their yards longer, by which they are enabled to spread an equal surface of sail in proportion. The leverage power of the masts and sails being reduced in proportion to their stability, they are also found to answer their purpose equally well; for as they are more in the open ocean, where the swell of the sea runs longer and higher (they are also seldom steered so close to the wind), although their sails are of a broader form, they stand with a good effect. In general, when the topsail is as broad at the lower reef as the depth between the main and topsail-yard, it is considered to be in the best proportion.

To Proportion the Yards of Ships to be employed in the Foreign Trade.

25th, *To find the length of the Main-Yard,* from which all the others are generally proportioned.—*Rule.* To the length of the load-water line, including the breadth of the main-stem and stern-post (which in most vessels is equal to the length taken for

tonnage),* add the ship's extreme breadth in feet and inches, and from this sum as a momentum, the length of the yards must be calculated; accordingly, to find the length of the main-yard, take 4-11ths of the length of the load-water line and extreme breadth added together, for the main-yard.

26*th*, *Main Topsail-yard*, 7-9ths of the main-yard.

27*th*, *Main Topgallant-yard*, 3-4ths of the main topsail-yard.

28*th*, *Main Royal-yard*, 2-3ds of the main topgallant-yard.

29*th*, *For the Diameter of the Yards.*—The diameter at the middle, or place of the slings of all the yards, is 1 inch for every 4 feet of their whole length. The outer ends are half the diameter of the slings or centre of the yard.

30*th*, That part of the yard without the cleats, called the *Yard's-arm*, is commonly about 1-20th of the full length of the yard.

Observation.—It was formerly the custom to have all the fore-yards about 1-20th or 1-18th part shorter than the main-yards, and the fore-top, and top-gallant masts in the same proportion; in which proportion it was considered that the head-sails were more easily managed, and also lighter on the fore part of the vessel. But it is now found to be a little more convenient to have the main and fore-top and top-gallant-sails of the same size, by which three topsails may often answer the purpose of having four, as required when the yards are of different lengths. The fore-mast is now set a little farther aft, which makes the vessel equally easy in the sea, and the only difference in the size of the sails by this arrangement is in the fore and main courses. Many shipmasters approve of the old method of having the fore-yards and fore-topmasts 1-20th shorter than the main-yards and top-masts. The main and fore-yards being of the same length and diameter, we have only to state, that

31*st*, *The length of the Mizen-yards* is 3-4ths of the length of the main-yards, and their diameters are in the same proportion, except that the lowest yard, commonly called the

32*d*, *Crossjack-yard*, is considerably smaller in proportion to its length, being only 1 inch in diameter for every 4½ feet of its full length.

33*d*, *The Spritsail-yard* is made the same, or 7-8ths of the length of the fore-topsail-yard, and its thickness is in nearly the same proportion, only a little lighter. This yard is used in small ships as a flying jib-boom, and may occasionally answer for a topsail-yard, if required.

34*th*, *Studdingsail-booms.*—The studdingsail-booms are about 2 or 3 feet longer than the half length of the yards to which they are fitted. Their diameter at the outer boom-iron is 1 inch for every 4 feet of their whole length, and the outer end 2-3ds of the thickness at the boom-iron; lined rounding the same as the yards, from the boom-iron to the outer end.

By the foregoing rules, the dimensions of all the principal spars, &c. of any ship may be calculated in a few minutes, and their simplicity and correctness is illustrated by the following example, and a reference to the mast and rigging-plan of the ship, *see Plate* XXVII.

* If the vessel has an upright stern-post and a raking stem, the length taken for register will exceed the length of the load-water line, by as much as the stem rakes-out above the load-water line; in this case, one-half of this rake must be added to the length of the load-water line, for the medium rake, and proceed as above stated.

Calculation for the Dimensions of the Masts, &c. of a Ship of 500 Tons.

The following are the calculations for the masts, yards, &c. of the ship of 500 tons, whose principal dimensions are—

	Ft.	In.		Ft.	In.
Length of keel,...............	106	6	Depth of hold,.....................	22	0
Ditto for tonnage,............	117	2	Housing of the masts,............	20	0
Breadth of frame,............	30	6	Length on the load-water line,	115	3
Ditto for tonnage,............	31	0			

1*st*, Main-mast, Main Top-masts, &c.—$31 \times 3 = 93 + $ 1-3d of 115 ft. 3 in. $= 131.5$, and 4-7ths of $131.5 = 75$ ft. 1 in. = length of main-mast; or by rule 2d, which is shorter, $115 \cdot 3 \div 3 = 38.5 + 30.5 \times 3 + 20 = 150$, and $150 \div 2 = 75$ feet = length of main-mast; $75 \times .3 = 22\frac{1}{2}$ inches, its diameter at the partners; 7-8ths of $22.5 = 19\frac{7}{8}$ in diameter at trestletrees; 2-3ds of $22.5 = 15$ in. its diameter at the top; and $75 \times .14 = 10.5$ feet, the length of the mast head.

Main Topmast,—4-7ths of $75 = 42$ ft. 10 in. the length of main-topmast; $42 \cdot 10 \div 3 = 14\frac{1}{4}$, its diameter at the heel; and 2-3ds of $14\frac{1}{4} = 9\frac{3}{4}$ inches, diameter at the top; and $42.9 \times .14 = 6$ feet, the length of the head.

Main Topgallant-mast,—5-9ths of $42 \cdot 10 = 23$ feet $6\frac{1}{2}$ inches, the length; and $23 \cdot 6 \div 3 = 7\frac{7}{8}$ inches, its diameter at the heel; 2-3ds of $7\frac{7}{8} = 5$ inches, its diameter at the top; and $23.5 \times .14 = 3$ feet 3 inches, the length of the mast-head.

Main Royalmast,—4-7ths of 23 feet 6 inches $= 13.5$ feet the length of the mast from heel to the rigging or pole; 3-5ths of $13.5 = 8$ feet 1 inch, the length of the pole; 5-8ths of $7\frac{7}{8}$ inches $= 5$ inches, its diameter at the heel; 2-3ds of $5 = 4$ inches nearly for the diameter at the rigging; and 3-5ths of $4 = 2\frac{1}{2}$ inches diameter at the truck.

Fore-masts, &c.—14-15ths of $75 = 70$ feet, the length of the Fore-mast, and $70 \times .3 = 21$ inches, its diameter at the partners; 7-8ths of $21 = 18\frac{3}{8}$, its diameter at the trestletrees, and 2-3ds of $21 = 14$ inches, diameter at the top; and $70 \times .14 = 9.8$ feet, the length of the mast-head.

Fore Topmast,—19-20ths of 42 feet 10 inches $= 40$ feet 8 inches, the length of the topmast; $40.8 \div 3 = 13\frac{7}{8}$ inches, its diameter at the heel; 2-3ds of $13\frac{7}{8} = 9\frac{1}{4}$ inches, its diameter at the top; and $40.7 \times .14 = 5$ feet 7 inches, the length of the mast-head.

Fore Top-gallant,—19-20ths of $23.5 = 22$ feet 6 inches, the length; $22.5 \div 3 = 7\frac{1}{2}$ inches, diameter at the heel; 2-3ds of $7\frac{1}{2} = 5$, diameter at the top; and $22.5 \times .14 =$ 3 ft. 1 in. for the length of the mast-head.

Fore-royal,—19-20ths of $13.5 = 12$ ft. 7 in. the length from the heel to the rigging or pole; and 3-5ths of $12 \cdot 7 = 7$ ft. 7 in. for the length of pole; 5-8ths of $7\frac{1}{2} = 4\frac{5}{8}$ in. the diameter at the heel; diameter at the rigging $3\frac{3}{4}$ inches; at the truck $2\frac{1}{2}$ inches.

Mizen-masts,—9-10ths of 75 feet $= 67 \cdot 6$, the length of the mizen, and 3-4ths of $22.5 = 16\frac{7}{8}$, diameter at the partners; 7-8ths of $16\frac{7}{8} = 14\frac{3}{4}$ inches, diameter at trestletrees, and 2-3ds of $16\frac{7}{8} = 11\frac{1}{4}$ inches, diameter at the top; and $67.5 \times .14 = 9$ feet, the length of the mast-head.

Mizen Topmast,—3-4ths of $42 \cdot 10$ inches $= 32$ feet 1 inch, the length; 1-3d of $32 \cdot 1$

$= 10\frac{3}{4}$ nearly, the diameter at the heel; 2-3ds of $10\frac{3}{4} = 7$ inches, diameter at the top; and 7-8ths of $10\frac{3}{4} = 9\frac{3}{8}$ inches, diameter at the trestletrees; and $32.1 \times .14 = 4$ feet 4 inches, length of the mast-head.

Mizen Top-gallant,—3-4ths of 23 feet 6 inches = 17 feet $7\frac{1}{2}$ inches, the length; $17.7\frac{1}{2} \div 3 = 5\frac{7}{8}$ inches or 6 inches, the diameter at the heel; and 2-3ds of $6 = 4$ inches, diameter at the top; also $17.7 \times .14 = 2$ feet 5 inches, length of the head.

Mizen Royal,—3-4ths of 13 feet 5 inches = 10 feet 3 inches, length from heel to the rigging; and 3-5ths of $10 = 6$ feet, length of the pole from rigging to the truck; 5-8ths of $6 = 4$ inches nearly, its diameter at the heel; 2-3ds of $4 = 2\frac{3}{4}$ inches, diameter at the rigging; and 3-5ths of $2\frac{3}{4} = 2$ inches nearly, its diameter at the truck.

Mizen-boom and Gaff,—$30.6 \times 1.2 = 36$ feet 6 inches, length of the boom, but may be a little longer, if desired; $36.5 \times .23 = 10.3$ inches, its diameter at the sheet; 2-3ds of $10.3 = 7$ inches, diameter at the tail of the cheeks, and 3-5ths of $10.3 = 6$ inches, diameter at the outer end; 2-3ds of $36.5 = 24$ feet 4 inches, the length of the gaff; $24.4 \times .24 = 5\frac{3}{4}$ or 6 inches, diameter at the tail of the cheeks, and $3\frac{1}{2}$ diameter at the outer end.

Main-gaff, the same as the mizen-gaff. *See the Rule.*

Fore-gaff, the same as the main-gaff.

Bowsprit,—1-3d of $115.3 = 38.6 + 31 = 69.6$, and $69.6 \div 2 = 34.9$, the length of the bowsprit without the stem; diameter at stem $22\frac{1}{2}$ inches, and 2-3ds of $22.5 = 15$ inches diameter at the outer end; 4-7ths of $34.9 = 20$ feet nearly, the distance of the cleats for the heart of the stay, from the stem.

Jib-boom,—$34.9 + $ 1-6th $= 40$ feet 2 inches, length of jib-boom, and $40 \div 3 = 13\frac{1}{2}$ inches, diameter at inner end; and 2-3ds of $13 = 8\frac{1}{2}$ inches, diameter at the outer end.

Main-top,—5-9ths of 31 feet = 17 feet 4 inches, the breadth of the top; $17.4 \div 2 =$ 8 feet 8 inches, the length of the trestletrees; 5-6ths of $20 = 16\frac{1}{2}$ inches, the depth of ditto; and 3-7ths of $16.5 = 7$ inches, the breadth of ditto; 17 feet 4 inches, the length of the crosstrees; $7\frac{1}{8}$ inches, breadth of ditto; 6 inches, the depth of ditto.

Cap,—$15 \times 3.5 = 4$ feet 4 inches, the length of the main-cap; $14\frac{1}{4} \times 1\frac{3}{4} = 2$ feet, the breadth of ditto; 10 inches, the depth of ditto.

Main Topmast Trestletrees,—8 feet 8 inches $\div 2 = 4$ feet 4 inches, the length; 10 inches, the depth; $4\frac{1}{4}$ inches, the breadth.

Main Topmast Crosstrees,—8 feet 8 inches in length by 4 inches square.

Cap for the Main Topmast,—$9\frac{3}{4} \times 3.5 = 2$ feet 10 inches, the length; $7\frac{7}{8} \times 1\frac{3}{4} = 13\frac{3}{4}$ inches, the breadth, by 6 inches in depth.

Main Top-gallant Trestletrees,—2 feet 2 inches, the length; 5 inches, the breadth; 3 inches, the depth.

Main Top-gallant Crosstrees,—4 feet 4 inches, the length; $2\frac{1}{2}$ inches broad by 2 inches deep.

Main Top-gallant Cap,—$4 \times 3.5 = 1$ foot 2 inches in length; 7 inches in breadth; 3 inches in depth.

The Tops, Trestletrees, Crosstrees, Caps, &c. for the Fore-mast, fore-topmast, fore-topgallant-mast, &c. are the same size as the main-caps, trestletrees, crosstrees, &c.

Mizen Top, &c.—3-4ths of 17 feet 4 inches=13 feet in length. Trestletrees 6 feet 6 inches in length; 5-6ths of $14\frac{3}{4} = 12\frac{1}{8}$ inches in depth; 3-7ths of $12 = 5\frac{1}{8}$ inches in breadth or thickness. 13 feet, the length of the Crosstrees; $10 \div 2 = 5$ inches, breadth or thickness of ditto; $4\frac{1}{2}$, depth of ditto ditto. $11\frac{1}{4} \times 3.5 = 3$ feet $3\frac{1}{4}$ inches, the length of the Mizen Cap; $10\frac{3}{4} \times 1\frac{3}{4} = 19$ inches, the breadth of ditto; 3-4ths of $10\frac{3}{4} = 8$ inches, the depth of ditto.

Mizen Topmast Trestletrees,—3 feet 3 inches in length; 5-6ths of $7 = 6$ inches nearly, the depth; 3-7ths of $6 = 3$ inches nearly, the breadth.

Mizen Top-mast Crosstrees,—6 feet 6 inches in length, $7 \div 2 = 3\frac{1}{2}$ inches in thickness, 3 inches in depth. $7 \times 3.5 = 24\frac{1}{2}$ inches or 2 feet, the length of mizen top-mast cap; $4 \times 1\frac{3}{4} = 7$ inches the breadth of ditto; $3\frac{1}{8}$, the depth of ditto.

Mizen Top-gallant Trestletrees,—1 foot 6 inches in length, 4 inches in depth, by 2 inches in breadth.

Crosstrees,—3 feet 3 inches in length; 5-6ths of $4 = 3\frac{1}{4}$ inches in depth, by $2\frac{1}{2}$ inches thick. $4 \times 3.5 = 14$ inches, the length of the mizen top-gallant cape; $3\frac{1}{2} \times 1\frac{3}{4} = 6\frac{1}{8}$ inches, the breadth of ditto; 3 inches, the depth of ditto.

Cap of the Bowsprit,—$15 \times 3.5 = 4$ feet 4 inches in length; $14 \times 1\frac{3}{4} = 2$ feet in breadth; 3-4ths of $14 = 10\frac{1}{2}$ inches in thickness.

Main Yards, &c.—$115 + 31 = 146$, and $146 \times \frac{4}{11} = 53$ feet 1 inch, length of the main-yard; $53 \div 4 = 13\frac{1}{4}$ inches diameter at the slings; $13\frac{1}{4} \div 2 = 7\frac{5}{8}$ diameter at the ends; $53 \div 20 = 2$ feet 7 inches, length of yard-arms. $53 \times \frac{7}{9} = 41$ feet 2 inches, the length of the main-top sail-yard; $41 \cdot 2 \div 4 = 10\frac{1}{4}$ inches, diameter at the slings; $10\frac{1}{4} \div 2 = 5\frac{1}{8}$ inches, diameter at the ends; $41 \cdot 2 \div 20 = 2$ feet, the length of the yard-arms, but may be a little longer if required. $41 \cdot 2 \times \frac{3}{4} = 30$ feet 10 inches, length the main top gallant-yard; $30 \cdot 10 \div 4 = 7\frac{3}{4}$ inches, diameter at the slings; $7\frac{3}{4} \div 2 = 3\frac{7}{8}$ inches, diameter at the ends; $30 \cdot 10 \div 20 = 1$ foot $6\frac{1}{2}$ inches, the length of the yard-arms. $30 \cdot 10 \times \frac{2}{3} = 20$ feet 6 inches, length of main royal-yard, $20 \cdot 6 \div 4 = 5\frac{1}{4}$ inches, diameter at the slings, $5\frac{1}{4} \div 2 = 2\frac{5}{8}$ inches, diameter at the ends; $20 \cdot 10 \div 20 = 1$ foot, the length of the yard-arms.

Fore-yards, &c.—All the fore-yards the same size as the main-yards.

Mizen-yards, &c. 3-4ths of the main-yards—$53 \times \frac{3}{4} = 39$ feet 9 inches, the length of the cross-jack yard; $39 \cdot 9 \div 4\frac{1}{2} = 8\frac{3}{4}$ inches, diameter at the slings, and $4\frac{3}{8}$ inches, diameter at the ends; $39 \cdot 9 \div 20 = 2$ feet nearly, the length of the yard-arms. $42\ 2 \times \frac{3}{4} = 30$ feet 10 inches, the length of the mizen topsail-yard; $30 \cdot 10 \div 4 = 7\frac{7}{8}$ inches, diameter at the slings $= 4$ inches nearly, diameter at the ends; $30 \cdot 10 \div 20 = 1$ foot 6 inches nearly, length of yard-arms. $30 \cdot 10 \times \frac{3}{4} = 23$ feet 1 inch, the length of the mizen top-gallant yard; $23 \cdot 1 \div 4 = 5\frac{3}{4}$ inches, diameter at the slings, and nearly 3 inches diameter at the ends; 1 foot, length of the yard-arms; $20 \cdot 6 \times \frac{3}{4} = 15$ feet $4\frac{1}{2}$ inches, the length of the mizen royal-yard; $15 \cdot 4 \div 4 = 4$ inches nearly, the diameter at the slings, and 2 inches diameter at the ends; 9 inches the length of the yard-arms.

Studding-sail Booms for the Main and Fore-yards.—Studding-sail booms for main-yards $53 \div 2 = 26 \cdot 6 + 2 = 28$ feet 6 inches in length, 7 and 5 inches diameters; ditto top-sail yards, $42 \div 2 = 21 + 2 = 23$ feet in length, 6 and 4 inches diameters; ditto top-gallant yards, $30 \cdot 10 \div 2 = 15.5 + 2 = 17$ feet 5 inches in length, $4\frac{5}{8}$ and 3 inches diameters.

On the Masts and Yards for Brig-rigged Vessels for the Foreign Trade.

35*th*, *The Masts and Yards for Brigs* are in every respect in the same proportion as the main and fore-masts and yards of a three-masted ship, but require to be as much larger as to enable them to spread equal sail upon a wind as a three-masted vessel of the same tonnage.

36*th*, *The length of the Main-mast* is generally the first thing determined upon, and it may be found by the same rule as that for the main-mast of a ship, (*see Rule* 1*st*), with this difference only, that it must be once its diameter longer than the ship's main-mast; or, *Rule* 2*d*, to 1-3d the length of the load-water line, add 3 times the ship's breadth, and multiply by .59, which will give the length of the main-mast in feet and inches. Or by the following method, which is considered rather more correct than the above:—*Rule*. To 1-3d the length of the load-water line, add three times the extreme breadth of beam, and the depth of the hold from the upper part of the main-deck to the top of the floor-timber amidship, and half that sum is the length of the main-mast in feet and inches. *Its diameter at the Partners*, one inch for every 3½ feet of its length, if made of Riga timber.

37*th*, *The length of the Main Topmast* is 5-9ths of the length of the main-mast.

38*th*, *The length of the Main Topgallant-mast* is 5-9ths of the length of the main-topmast.

39*th*, *The Main Royal-Mast* to the pole is 4-7ths of the main topgallant-mast, and the length of the pole from the rigging to the truck is 3-5ths of the length from the rigging to the heel.

40*th*, The diameters and lengths of the heads of all these masts are in the same proportion as those for three-masted vessels; that is, for the length of the head, take 5 inches for every three feet of the full length; or 1-7th of the length of the mast gives the head 1½ inches longer on a length of 56 feet.

41*st*, *The Brig's Fore-mast.*—The fore-mast is generally about 14-15ths of the length of the main-mast.

42*d*, *The Fore-topmasts* bear the same proportion to the main-topmasts, as the fore-topmasts to the main-top and topgallant-masts of a ship.

43*d*, *For the length &c. of the Yards of Brigs in the Foreign Trade.—Rule*. Find the length of the load-water line as before directed, to which add the ship's breadth in feet and inches. As the masts in brigs commonly stand a little farther apart than those in ships, (for as they must spread the same quantity of sail as a three-masted vessel of the same tonnage, it is necessary to increase the length of the yards in proportion to the difference between the masts of a brig and a three-masted vessel), 3-8ths of the length of the load-water line, adding the breadth of the beam, is a suitable proportion for the length of the main-yard; at most, it should not exceed the product of the main length and breadth multiplied by .39. A brig may be rigged so square that the length of the main and fore-yards added together is equal to the length of the load-water line, but should not much exceed this last proportion.

44*th*, The length of the *main-topsail*, *main-top-gallant*, and *main-royal-yards* are diminished in the same proportion as those for a ship.

45*th*, *The length of the Fore or Head-yards* is sometimes reduced 1-18th of the length of the main-yards, but are now commonly the same length as the main-yards, for the convenience of changing the sails from the main to the fore-yards.

46*th*, *The dimensions of the Bowsprit, Jib-booms, Caps, Tops, Trestletrees, Crosstrees,* &c. are all in the same proportion as those for three-masted vessels.

On the Dimensions of the Masts and Spars of Ships and Brigs adapted for the Coal or Coasting Trade.

These vessels are sometimes rigged ships, but more frequently brigs or snows. Their masts differ very little in length and diameter from the dimensions we have already given; but their yards are generally shorter, and of rather a stouter proportion, being as thick in the middle or slings, as yards of the common length for ships employed in the foreign trade. In finding the length of the main-yard for these vessels, it will be necessary to use the same general dimension of the ship, *i. e.* the length of the load-water line and the breadth. Vessels in the foreign trade have the length of their main-yard 3-8ths of this sum; but there are many vessels in the coal-trade the length of whose main-yards very little exceeds 1-3d of the load-water line. The following may be allowed to be a fair proportion :—

47*th*, *To find the length of the Main-yard.—Rule.* Multiply the length of the load-water line, adding the breadth, by .34, for the length of the main-yard.

48*th*, *The length of the Main-topsail-yard* is 4-5ths of the main-yard.

49*th*, *The length of the Main-topgallant-yard* is 3-4ths of the main-topsail-yard, or when the topgallant-yard is to be of a light dimension, 7-10ths of the main-topsail yard may be allowed.

50*th*, Their diameter in the middle is one inch for every 3½ feet of the whole length, or 2-7ths of the length, taking inches and parts for the length in feet and inches.

60*th*, The proportions for the Fore-yards are the same as for the main-yards.

61*st*, Jib-booms, Main-boom, Gaff, Caps, Crosstrees, Trestletrees, Tops, &c. are all in the same proportion as other vessels.—*Observation.* Their main-booms are however seldom longer than to come square with the taffrail, and partly on this account their main-mast is placed a little farther aft than those of other vessels.

On the Dimensions for Masts and Spars of Schooners.

Schooner-rigged vessels have two masts, but these are of a very different proportion from those of a brig, the masts of a schooner being nearly as long as those for a sloop or smack-rigged vessel of the same tonnage. The principal design of the two masts in the schooner is to divide the sails into smaller portions, particularly the main-sail.

The schooner's main-sail is set with a boom and gaff; they have two fore-sails, called the boom and stay fore-sail. The boom fore-sail is set with a boom and gaff, or sometimes with a gaff only, and sheets. The stay fore-sail is made to run up upon the fore-stay, which is fixed either to the stem-head, or a short way out upon the bowsprit, with a jib without the fore-sail; also, a square-sail set with yards, ropes, &c. These used formerly to be the principal sails of a schooner, and the advantages of the rigg are, that

by it the vessel sails close to the wind, the sails are easier managed and worked in narrow channels, and with much less tear and wear than smacks or sloops. The rigg of schooners has, however, been considerably altered within these late years. In addition to the above, they now a gaff-topsail aft, square topsail and topgallant-sail on the fore-mast, jib-boom, flying jib-boom, square-sail, studding-sails, &c.

62*d*, *To find the length of the Main-mast for a Schooner.*—*Rule.* To three times her extreme breadth, add 1-3d of the length of the load-water line, and the depth of the hold from the deck to the upper part of the keel, and 2-3ds of the sum is the length of the main-mast. Or, to find the length above deck.—*Rule.* Multiply the momentum (*i. e.* the sum of 1-3d of the load-water line three times the breadth and the depth) by .55, the product is the length above deck.—*Example.* Suppose the length of the load-water line 72 feet, breadth per register 22 feet 4 inches, depth of the hold as above 13 feet 6 inches; then 22 ft. 4 in. × 3 = 67, and 67 + 72 ÷ 3 + 13 · 6 = 104 · 6, and 2-3ds of 104 · 6 is 69 · 8. Or, for the length above deck 104.5 × .55 = 57.5; then, length above deck 57 · 6 + 13 · 6 depth of the hold, = 71 feet, the length, a little longer than by the first rule. Or, by a rule which I used formerly to employ, viz. add 1-4th of the depth of the hold from deck to the limbers, to three times the breadth of the midship frame; the sum is the whole length of the main-mast, in a very suitable proportion for regular built schooners. However, the two first methods will be found to produce the best general proportion, whether the vessel be of a long or short construction.

63*d*, *The Fore-mast.*—The fore-mast is generally from 17-18ths to 19-20ths of the length of the main-mast.

64*th*, *Length of the Mast-heads,* from the lower part of the trestletrees to the top, is—1*st*, for the main-mast, 2-13ths of the full length of the mast; 2*d*, for the fore-mast, 1-5th of ditto.

65*th*, *The Diameter at the Partners.*—For the main-mast, 1 inch for every 4 feet of the full length; for the fore-mast, 1 inch for every 3½ feet of the full length.

66*th*, *Length of the Topmasts,* from the heel to the rigging,—each half the length of the fore-mast.

67*th*, *Length of the Poles,* about 1-6th of the topmasts.

68*th*, *The Diameter of the Topmasts at the Cap* is one inch for every 4 feet of the length from the heel to the pole or rigging.

69*th*, *The Length of the Yards.*—To the full length of the load-water line, add the ship's breadth per register; multiply the sum by .44 for the length of the fore-yard; or, by another rule, make the length of the fore-yard 4-9ths of the above momentum.

70*th*, *The Fore-topsail-yard* is 3-4ths of the fore-yard.

71*st*, *The Fore-topgallant-yard* is 3-4ths of the topsail-yard.

72*d*, *The Diameter of the Fore-yards at the Slings* is one inch for every 4 feet 8 inches of their length, or 3-14ths of the length, inches for feet.

73*d*, *The Topsail-yard and Topgallant-yard,* one inch for every 4 feet of their length.

74*th*, *The Lengths of the Bowsprit and Jib-boom,* without board, are the same as for a brig.

75*th*, *The Diameter of the Bowsprit* at the stem-head, the same as the fore-mast at the partners.

76*th*, *The Diameter of the Jib-boom*, the same as a brig's or ship's, *i. e.* one inch for every 3 feet of its length.

77*th*, *The Main-boom* is as long as to have 1-3d of its length abaft the sheet.

78*th*, *Its Diameter at the Sheet*, one inch for every $4\frac{2}{3}$ feet of its length.

79*th*, *The Gaff* is 2-3ds of the length of the boom.

80*th*, *Its Diameter at the tail of the Cheeks*, one inch for every 4 feet 4 inches of its length. The other light spars are proportioned at fancy.

81*st*, *To find the Length of the Mast, &c. for a Smack.—Rule.* To half the length of the load-water line, add three times the breadth per register; also the depth of the hold from the deck to the under side of the floors, or upper side of the keel; and 5-8ths of this sum will be the length of the mast.—*Example.* Suppose the length 74 feet, the breadth 23 feet 8 inches, and depth 13 feet 6 inches; then $74 \div 2 = 37$, and $23 \cdot 8 \times 3 = 71$; then $37 + 71 + 13 \cdot 8 = 121 \cdot 8 \div \frac{5}{8} = 76$ feet.

82*d*, *The Diameter of the Mast*, Riga spar, one inch for every $3\frac{1}{2}$ feet of its full length.

83*d*, *The Length of the Mast-head*, 1-6th or 2-13ths of the length of the mast.

84*th*, *The Length of the Topmast* is equal to the length of the mast from the deck to the cross-trees.

85*th*, *The Diameter of the Topmast*, at the cap, is one inch for every 5 feet in length.

86*th*, *The Length of the Bowsprit* is 2-3ds of the ship's length per register, or 2-3ds of the length of the load-water line; or, as allowed by act of Parliament, 2-3ds of the length on deck.

87*th*, *The Diameter of the Bowsprit at the Stem* is 4-5ths of the diameter of the mast at the partners.

88*th*, *The Length of the Main-boom* is commonly made equal to the length of the ship's keel, but will be found more correctly by multiplying the length of her load-water line by .92.

89*th*, *The Diameter of the Main-boom*—1*st*, at the sheet, is 2-9ths of the length, taking inches for feet, or 1 inch for $4\frac{1}{2}$ feet of its length; 2*d*, at the tail of the cheeks or mast, 2-3ds of the sheet diameter.

90*th*, *The Length of the Gaff* is 2-3ds of the boom.

91*st*, *The Diameter of the Gaff*—1*st*, at the tail of the cheeks, one inch for every $3\frac{1}{2}$ feet of its length; 2*d*, at the outer end, about 6-10ths of the diameter at the cheeks.

92*d*, *The Length of the Cross-jack Yard* is about 9-12ths of the length of the load-water line; or if this should be thought rather long, multiply the length of the load-water line by .72 for the length of the cross-jack yard.

These, then, are the rules and proportions for calculating the dimensions of all the principal masts, yards, &c. of the different classes of merchant vessels, which, from their simplicity, may be easily retained on the memory. I have thought it unnecessary to insert a table of the dimensions of masts, &c. for the different classes of ships, which indeed, on account of their various proportions of length, breadth, &c., cannot be properly regulated by their tonnages. I consider the tables of the dimensions of masts,

&c., that are commonly given in works of this kind, to be of very little use in regard to merchant vessels generally. In the first place, because they are not calculated by any invariable rule, according to the tonnages of the vessels, and are therefore very irregularly proportioned; and in the second place, because, although they were so calculated, the tonnage cannot be taken as a fair data, for it is evident that many vessels of the same tonnage per register are very different in the proportions of length and breadth. Therefore, on all these accounts, and the principles already explained, I trust it appears evident to the reader, that the best and most certain principle of finding the dimensions of the masts and spars of vessels is by a rule applicable to all sizes of vessels, according to their proportions of length and breadth.

Placing the Masts.

The placing of the Masts in their best situation is a point of great importance, as it affects the steering, working, and sailing of the ship.

I have never seen any correct rule for placing the masts in the different classes of shipping; neither do I believe that any perfect rule for this purpose will ever be obtained, owing to the great diversity in the constructions and purposes for which vessels are built. Also, as the sailing is not only affected by the different depths to which they are loaded, but also by the roughness of the waves, and varying skill of commanders.

However, from the opinion of able seamen and commanders of vessels, and from my own experience at sea, I can fully recommend the following methods of placing the masts. Upwards of fifty or sixty merchant vessels have had their masts placed by them, and with a very few exceptions they have been found to answer uncommonly well.*

The largest of our vessels have seldom more than three masts. It is by the number of the masts, and the particular cut of their sails, that they are denominated. Thus vessels with three masts are called Ships or Barks—with two masts, Brigs, Schooners, or Shallops—with one mast, Sloops, Cutters, or Smacks.

First, to find the place of the Masts in a Ship or Bark.—The load-water line is to be considered the principal line of bearance of the ship; therefore the stations of the masts are all to be determined on this line—for which purpose, set the centre of the Main-mast 1-15th of the whole length abaft the centre or middle of the ship's length—the centre of the Fore-mast one-eighth of the length of the ship (per load-water line) aft from the fore edge of the rabbet of the stem on the same. But if the vessel has a very full or sharp bow, this dimension may be a varied a little to answer the construction of the same. The place of the Mizen-mast on the load-water line is 3-8ths of the distance between the after edge of the rabbet of the stern-post and the centre of the main-mast, set forward from the rabbet of the stern-post. The rakes of these masts are—

* The substance of the following rules for placing the masts has heretofore been given, with the directions for completing the draught on the paper; but as they are there given without any remarks, it has been thought proper to repeat them here, with such observations on this point as may tend to make them generally applicable to all vessels, whether of a lean or full construction.

1st, The Fore-mast should rake aft $\frac{1}{4}$ inch to the foot of its length.
2d, The Main-mast . . . . $\frac{1}{2}$ ditto ditto.
3d, The Mizen-mast, ... 1 ditto ditto.

To place the Masts in a Ship by another method.—Divide the length on the load-water line into 7 equal parts; set the Fore-mast its diameter before the first division from the stem; the Main-mast on the fourth division from the stem; the Mizen-mast its diameter before the sixth division. By this method, the main-mast is nearly in the same place, but the fore-mast is a little farther aft, and the mizen is a little nearer the stern. The fore-mast in large ships of war is commonly placed as far forward as 1-9th of the ship's length on the load-water line abaft from the stem on the same. I consider 1-8th the best proportion, 1-9th being rather too far forward, and 1-7th rather too far aft.

To place the Masts in a Brig or Snow.—Place the centre of the Main-mast 1-8th of the length of the load-water line abaft the centre of the ship on the same; the Fore-mast 1-6th of the length of the load-water line aft from the fore edge of the rabbet of the stem on the same, or 1-3d of the length of the load-water line before the middle of the ship. But in vessels which have a fine sharp run, with a good full buttock at the water's edge, the Main-mast may be set as far aft as 1-7th of the length of the load-water line abaft the centre of the ship on the same. Also observe, that if the vessel is very thin or narrow on the bow about the harpins, the Fore-mast should have a little more rake aft than common. The rake of the masts for brigs is the same as for ships, *i. e.* the fore-mast 1-4th of an inch to a foot—main-mast half an inch, or 3-4ths of an inch to a foot.

To place the Masts in a Schooner.—Place the main-mast 1-8th of the length of the load-water line abaft the centre of the ship's length on the same; the Fore-mast 2-9ths of the same length abaft from the fore part of the rabbet of the main stem, or 2-7ths before the centre of the ship's length on the same.

Rake aft of the fore-mast, 3-8ths of an inch to every foot of its length.
„ „ main-mast 3-4ths ditto, ditto, ditto.

To place the Mast in a Smack or Sloop.—Draw the length of the load-water line; mark its centre between the fore part of the rabbet of the stem and stern-post; then 1-7th of the length before the middle is the centre of the mast; or place it one-half between 1-3d and 3-8ths of the length aft from the stem. It should have a rake aft of half an inch to the foot.

The station of the bowsprit is determined by the height of the stem, and the rake is determined or effected by the housing, but commonly runs thus:—

For a Ship, the stave is from 4 to 5 inches to the foot.
„ Brig, do. - - 4 do. do.
„ Smack, do. from 1 to $1\frac{1}{2}$ do. do.

The place of the masts being now determined on the load-water line, it must be considered that any alteration from the proper rake will produce an effect similar to that of shifting their station; because the principal action or centre of effort is situate (supposing the small sails taken in and the ship under whole topsails) about the height of

the main-yard. Therefore the true situation of the masts, with respect to the part of the vessel immersed, will be where a plumb-line suspended from the centre of effort touches the surface of the water, or load-water line; so that if we alter the rake of the masts, it will have nearly the same effect as altering their station on the deck.

As a farther guide for placing the masts and giving them their proper rake—*Observe*, That the distance between the centre of the fore-mast and main-mast, at the height of the main-yard, is between 8-11ths and 3-4ths of the length of the load-water line, and that the distance between the main and mizen-mast, at the same height from the deck, is from 5-8ths to 2-3ds (but 2-3ds is the best proportion when it can be obtained) of the distance betwixt the fore-mast and main-mast; also, that the centre between the mizen-mast and the fore-mast, at that height, is perpendicular to the middle of the ship's length on the load-water line.

On the Properties and Dimensions of the Standing-Rigging.

Having treated on the side-pressure of the sails and the principles of masting, and laid down rules for proportioning the masts, yards, &c. and also directions for placing the masts in the different kinds of vessels, I shall next direct the reader's attention to the means employed for supporting the masts, and the properties of the standing-rigging.

The Standing-rigging consists of all the ropes that are attached to the hull of the vessel, for the support and security of the masts, topmasts, bowsprits, &c. These ropes are commonly denominated shrouds, topmast-shrouds, stays, back-stays, &c. On these ropes, the security of the masts and bowsprits, &c. is chiefly dependent, and our present object is to point out some regular method of ascertaining the proper size, in proportion to the different classes of shipping. The proportioning of the standing-rigging, like the masts, has heretofore been generally confounded by a variety of opinions,—some considering light rigging the most advantageous, and a saving in the expense of the outfit of the ship; others approve of strong rigging, as a better security to the masts—they also consider it less expensive in the end. Accordingly, I have found a wide difference in the size of the standing-rigging of vessels of the same tonnage; in some instances, I have found the strength of the ropes employed as standing-rigging varying, in vessels of the same tonnage, in nearly double proportions—to such extremes do the above opinions lead.

To establish some general rule for the size of the standing-rigging, I have consulted a number of the most experienced captains of vessels on this subject, and procured the dimensions of the standing-rigging of a number of vessels which have been rigged in the different ports of Great Britain, for the purpose of obtaining correct data from which to proportion the standing-rigging of all vessels.

Many of the captains with whom I have had an opportunity of conversing on this subject are of opinion, that vessels are in general fitted with too small standing-rigging, particularly for the lower masts. And we may likewise infer, from a proper investigation of the effects produced, and advantages obtained, by different proportions of rig-

ging, that the rigging which is considered rather weak rigging is neither so safe or profitable as that which is sufficiently strong to bear with ease the greatest strains to which it is likely to be exposed; because any rope which is exposed to a constant strain is continually diminishing in its strength, in proportion to the strain and the quantity of the material exposed to it. And as the shrouds and stays are constantly exposed to a certain tension, independent of the strains which are produced by the side-pressure of the sails in gales of wind, which often continue for such a length of time as to diminish the strength of any rope, and particularly such as are considered in a light proportion, we see the necessity of employing rigging which will be able to bear with ease at least one half more than the greatest strains which are likely to be thrown upon it. And farther, as the standing-rigging is of the greatest moment to the security of the masts, it should also be of such a strength as to prevent it from over-stretching, which is frequently the case with rigging which is too weak or loosely laid up, the effect of which is frequently the loss of masts, bowsprits, or the like. Sometimes the loss of the vessel is occasioned by the over-stretching of the shrouds, which in many cases may be as fatal as if they had actually broke or given way, for by both the masts are deprived of the requisite support. When the rigging is sufficiently strong, it is not only less liable to break, but at all times keeps at a more regular strain, so that it does not require to be so often set up or tightened, and therefore retains its strength for a much longer period.

It is proved by experience, that a ship sails much faster when the masts are allowed to have a little play, than when secured by rigging which is set up to its full stretch; therefore, if it is sufficiently strong, there will be less occasion to have the shrouds brought to a full state of tension, but only to be kept at a moderate tightness. In this case, they are not so liable to stretch or be broken by the pressure of the sails on the mast.

Before proceeding to consider the proportion of the standing-rigging, I shall first shew the methods of calculating the weight and strength of ropes, according to their girths or thickness.

In the first place, observe that the superficial contents of circles are in proportion to the squares of their diameters, and also as the squares of their circumferences.

A rope of 1 inch circumference, and 486 fathoms long, weighs one cwt.; consequently, to find the length of any other rope, which will make the same weight, we have only to square the girth of the given rope, and divide 486 (the length of the one-inch rope) by it, and the quotient is the length required in fathoms, feet, and inches.

Example.—What length of a six-inch rope will be required to weigh 1 cwt.?— $6 \times 6 = 36$, and $486 \div 36 = 13$ fathoms 3 feet.

Example 2d.—How many fathoms of $8\frac{1}{2}$-inch rope is required to weigh 1 cwt.?— $8\frac{1}{2} \times 8\frac{1}{2} = 72\frac{1}{4}$, and $486 \div 72\frac{1}{4}$. But as the square of the girth is $72\frac{1}{4}$, bring both into quarters, $486 \div 72\frac{1}{4} \times 4 = 1944 \div 289 = 6$ fathoms 4 feet 4 inches, the length required.

Problem 2d, To find the difference of weight or strength of one rope from another, according to their girths.—*Rule.* Square the girths; divide the squares of the one by the squares of the other; the quotient is the difference of weight or strength.

Example.—Given, two ropes, one 4 and the other 8 inches girth; required, their proportional weight and strength?—$4 \times 4 = 16$, and $8 \times 8 = 64$, and $64 \div 16 = 4$, the comparative strength being 4 to 1.

Problem 3d, To find the weight of any length of rope of a given girth.—*Rule.* Square the girth in inches, multiply by the length of the rope in fathoms, feet, and inches, and divide the product by 486 for the weight in cwts. qrs. and lbs.

Example.—Required the weight of 64 fathoms of six-inch rope?—$6 \times 6 = 36 \times 64 = 2304$, and $2304 \div 486 = 4$ cwt. 2 qrs. 26 lbs.

Note.—It is found that 1-4th of the square of the girth in inches is the weight in cwts. &c. of 121 fathoms of any common rope. Also, if the square of the girth be multiplied by .26, it will be nearly the weight in lbs. of the rope per fathom. Any good hempen rope is supposed to be able to bear without being injured about 800 times the weight of one fathom of its length.

Problem 4th, To proportion the strength of the rigging of one vessel by that of another, so as to have any number of shrouds, either more or less than the given ship.—*Rule.* Square the girth of one of the given shrouds, multiply it by the number of shrouds, then divide the product by the required number, and the square root of the quotient is the girth of one of the shrouds as required.

Example.—A smack of 190 tons having four nine-inch shrouds on a side; required, the girth of rope to make six on the side of equal strength to the four nine-inch ones?—$9 \times 9 = 81 \times 4 = 324$, and $324 \div 6 = 54$, and $\sqrt{54} = 7.34$, nearly $7\frac{3}{8}$ inches for the girth of six shrouds of equal strength to four nine-inch ditto.

Example 2d.—A brig of 360 tons, having 11 shrouds of $8\frac{1}{2}$-inch girth on a side; required, the girth to make nine on the side of equal strength?—Then $8.5 \times 8.5 = 72.25 \times 11 = 794.75$, and $794.75 \div 9 = 88.30$, which is the square wanted; then $\sqrt{88.30} = 9.39$, which is a little more than $9\frac{3}{8}$ inches for the girth of nine shrouds of equal strength to eleven $8\frac{1}{2}$-inch shrouds.

Example 3d.—Required the girth of the shrouds of the above brig, supposing we wish to have 13 on a side? Then $794.75 \div 13 = 61.13$, the square root of which is 7.81, or very near $7\frac{7}{8}$ inches for the girth required.

Problem 5th, To find the girth of any number of ropes, supposing them to be of different sizes, that shall be equal to any other number of ropes, either of the same or of different strengths.—*Rule.* Find the momentum or sum of the squares of all the given ropes. If they are all of the same size, square the girth of one, and multiply it by their number; if of unequal size, square the girth of each, and add them together for the momentum. If the required number of ropes are to be all of the same size, divide the momentum by their number; the quotient is the square of the girth of one, the square root of which is the girth sought. But if the required ropes are also to be of different strengths, such as one-half, 1-3d, 1-4th, &c. of each other, the largest must be first reduced to the same denomination as the smallest, and the momentum divided by the number of parts; then the quotient is the square of the smallest rope, and its square root is the girth.

N. B.—If the momentum is reduced to the same denomination as the divisor, the quotient is the square of the largest ropes

Example.—Suppose the momentum of the squares of the fore, main, and mizen-mast shrouds of a ship of 420 tons to be 912, and to have twelve shrouds of equal size on the fore and main-masts, and four on the mizen-mast, of half the strength each of those on the fore and main-mast; required, their girths?—Momentum of the squares is 912, per question. Number of one size for the main and fore-mast is 12, and 12×2 to reduce them to the same as the mizen-shrouds, of which there are 4; $12 \times 2 = 24 + 4 = 28$, and $912 \div 28 = 32.57$ = the square of one of the mizen-shrouds; and $\sqrt{32.57} = 5\frac{3}{4}$ inches for the girth of the mizen-shrouds. Now the square of the main and fore-shrouds is double the mizen; $32.57 \times 2 = 65.14$, and $\sqrt{65.14} = 8$ inches fully for the girth of the main and fore-shrouds, as required.

After the above methods of finding the weight and comparative strength of ropes, I shall, by the following example, shew in what manner that portion of the register tonnage is obtained which is taken for the momentum, which produces data for computing the strength of the lower or standing rigging of the different classes of shipping.

Having procured the dimensions and tonnage, the number and girths of all the standing-rigging of a great many vessels that had been built and rigged in different places, and arranged the girths of all the shrouds on one side of the vessel, taking the number on each mast, I squared them, and adding them together, found the sum of the squares or momentum for the strength of rigging on one side of each vessel; and dividing this by the tonnage, I found what proportion the one bore to the other, which was indeed very different, and seemed not to have been regulated by any rule to the various classes of shipping. Having discovered this, I added the tonnage of all the vessels together, and the sum of the squares of their rigging on one side, and dividing the latter by the former, found that $2\frac{1}{8}$ times the number of register tonnage of any three-masted vessel may be taken as a general proportion for the squares of the girths of all the lower shrouds on one side.

The following Table is an abridgment of the original from which the above data were procured; and it will be observed that these few vessels produce the same proportions.

TABLE of the TONNAGE, DIMENSION, and PROPORTION of the Lower Rigging of Five Vessels.

Ships' Names.	Ports where fitted out.	Register Tonnage.	Masts.	No. of Shrouds.	Girths of the Shrouds.	Squares of the Shrouds.	Momentum.	Parts.
William and Ann,	Leith,	385	Main and Fore,	12	8 in.	768	873	$2\frac{1}{4}$
			Mizen,	4	$5\frac{1}{8}$ „	105		
Fame,	Hull,	377	Main and Fore,	12	9 „	972	1116	$2\frac{7}{8}$
			Mizen,	4	6 „	144		
Portland,	Bristol,	385	Main and Fore,	10	$7\frac{1}{4}$ „	525	624	$1\frac{5}{8}$
			Mizen,	3	$5\frac{3}{4}$ „	99		
North Pole,	Leith,	313	Main and Fore,	10	$7\frac{1}{8}$ „	507	639	2
			Mizen,	4	$5\frac{3}{4}$ „	132		
North Briton,	Bristol,	402	Main and Fore,	12	$7\frac{1}{2}$ „	675	784	$1\frac{7}{8}$
			Mizen,	4	$5\frac{1}{4}$ „	109		
Amount of Tonnage,		1862				Sum of the squares,	4036	

Now, by dividing the sum of the squares by the amount of tonnage, we have $4036 \div 1862 =$ to $2\frac{1}{8}$ times the number of tons per register for the momentum or main sum of

the square of all the lower shrouds on one side of the ship. Although it is a general practice to take the dimensions of the masts as data for computing the strength of the shrouds and other principal ropes for the support of the masts, &c. yet it is generally allowed to be erroneous; for it is evident that by it the smallest masts are often fitted with the slightest shrouds, which is certainly the reverse of what is of necessity required. All the masts on which sails are set should be able to support a power equal to the stability of the ship, which will act upon them at the deck or partners as a fulcrum, and be sufficient to break any mast with the smallest sail that is set, if unsupported by the rigging; hence the principal reason of employing the shrouds and stays for their support, without which no mast would be able to stand even the rolling of the ship, unless made of such thickness as to render them burthensome to the vessel; whereas a comparatively small piece of timber will be sufficient to carry the vertical weight of the sails, and when properly supported with shrouds, to withstand the side-pressure occasioned by the wind on the sails.

The shrouds, being attached to the sides of the vessel and such parts of the mast as render them the best support consistent with other necessary equipments for the proper management of the sails, thus serve a most important purpose.

It has frequently been observed, that masts which were unable to bear their own weight, should the vessel heel to one side, have stood for several voyages acting only as a column to support the vertical weight of the yards, sails, &c.; the shrouds and stays having to resist the whole pressure of the wind on the sails, and every other strain occasioned by the rolling of the vessel. Hence a bad mast may stand for a considerale time when properly supported by the shrouds and stays; whereas the best of masts are soon sprung or carried away by the over-stretching or breaking of bad or weak rigging.

As before observed, the strain upon the mast is occasioned by the action of two opposite forces, which are in proportion to the strength of the wind, and the stability of the vessel; the masts, unless supported by the rigging, are unable to bear against the force of the wind and the stability of the ship; consequently the shrouds should be of sufficient strength to heel or cant the vessel, in opposition to her power of stability, but in all cases rather to give way than completely overset the vessel.

Now, as the length, breadth, and depth are the principal dimensions by which the stability is produced, and as from these dimensions the tonnage is computed, we may in general consider them as data by which to proportion the strength of the standing-rigging. The tonnage or size of the vessel is of course the first thing determined upon in commencing to build; and farther, as the tonnage of the ship per register is always known by the captain and mate of any vessel, it is the most convenient data in their hand to enable them to proportion their rigging, either for the repairs of old, or the outfit of new vessels. The following are the rules for producing the main strength of the shrouds, &c. of the different classes of shipping.

In the first place, it may be observed that the number of the masts makes little difference with respect to the strength of the ropes required for supporting them, in proportion to the size of the ship, or different classes of shipping. However, it may be necessary to increase the momentum by the 1-8th part of the tonnage for ships.

For the Dimensions of the Shrouds, &c. of a Smack.

I shall, by way of the first example, propose a smack or one-masted vessel of 180 tons. The tackle-pendant is commonly the same size as the shrouds. The vessel is 180 tons register, and has four 9-inch shrouds, and the tackle-pendant being the same size, makes five 9-inch ropes for supporting the masts. Then $9 \times 9 = 81 =$ the square of one shroud; 81×5, the number $= 405$, which number is exactly $2\frac{1}{4}$ times the number of register tons of the vessel. Hence this general rule for finding the strength of the shrouds and pendant for supporting the masts of any sloop or smack-rigged vessel, according to her tonnage.—*Rule.* Double the number of the register tonnage of the vessel, increase the sum by 1-4th, divide by the number of shrouds on one side, including the tackle-pendant, and the square root of the quotient is the girth of the rope, in proportion to the size of the vessel.

Example.—Required, the girth of the shrouds for a smack of 140 tons register, to have four shrouds on a side?—$140 \times 2\frac{1}{4} = 315$, and $315 \div 6 = 63$, and $\sqrt{63} = 7\frac{7}{8}$ inches for the girth of the shrouds as required.

The square roots in all the operations may be found extracted to inches and eighth parts for different numbers, by referring to the table of squares and cubes, page 66.

For the size of the Main-stay.—The square root of the number of tons per register is the girth of the main-stay; or make it equal in strength to $2\frac{1}{2}$ of the shrouds.

For the Spring-stay.—The spring-stay should be of equal strength to one of the shrouds, so that the main and spring-stay for a smack is equal to $3\frac{1}{2}$ shrouds. Thus the girth of the shrouds is a little more than $7\frac{7}{8}$ inches, its square being 63, which multiplied by $3.5 = 220$, for the squares of the girth of three shrouds = to the girth of the main and spring-stay. Again, the square of the main-stay, according to the above rule, is 9-10ths of the tonnage, and 9-10ths of $140 = 126$, the square root of which is $11\frac{1}{4}$ inches = the girth of the main-stay. The spring-stay being equal to the girth of one of the shrouds, the square of which is 63; now, $126 + 63 = 189 =$ the square of the three shrouds.

For the Dimensions of the Rigging for a Schooner.—Rule. Take $2\frac{1}{8}$ times the number of the register tonnage of the vessel for the momentum of the squares of all the shrouds on one side, which sum divide by the required number of shrouds, and the square root of the quotient is the girth of the shrouds.

The Fore-stay.—The square root of 2-3ds of the number of register tons of the vessel is the girth of the fore-stay.

The Main-stay, when leading to the head of the fore-mast, is half the strength of the fore-stay, or the same as one of the shrouds.

The Bob-stay.—The squares of the bob-stay is 2-3ds of the squares of the fore-stay.

For the Dimensions of the Riggingfor a Brig.—For a brig, twice the number of her tons register is the medium data, which being divided by the number of shrouds on a side, you have the square of one shroud, and the square root of the same is the girth.

Example.—Suppose a brig of 300 tons register; required, the girth of her shrouds, to have 11 on each side?—then $300 \times 2 = 600$, and $600 \div 11 = 54.54$, and $\sqrt{54.54} = 7.38$, nearly $7\frac{3}{8}$ inches for the girth, as required.

The Main-stay.—The square root of 1-3d of the register tons is the girth of the main-stay. The fore-stay is commonly the same size as the main-stay, but should be a little stronger, as 2-5ths of the register tonnage of the vessel.

For the Topmast Back-stays.—For the squares of the girth of the topmast back-stays on one mast, take 1-5th of the number of register tons; if to have only one back-stay, take the square root of that sum; if to have two, take the square root of its half for the girth of one stay.

For the Main Topmast-stay, take 1-6th of the number of the register tonnage for the squares of the girth, which may be either made as one, or divided into two, in manner of stay and spring-stay.

For the Fore Topmast-stay, take 1-5th of the number of the register tonnage of the ship for the squares of the girth, which may also be divided into two stays, as stay and spring-stay.

For the Topmast-shrouds,—1-3d of the tonnage per register is the square of the girths of all the topmast-shrouds on one side of both masts; divide this by the number of shrouds, and the square root of the quotient is the girth required. If only wanted for one mast, take half the above sum, and proceed as before.

For the Bob-stays,—take 1-3d of the register for the squares of all the bob-stays, which may be divided into as many parts as found convenient.

Fore-stays,—1-3d of the register tonnage is also the square of the fore-stay.

To find the Dimensions of the Rigging for a Ship.

Although the greatest part of the rigging of a ship is similar to that of a brig, yet a little difference is required in the momentum of the squares of the shrouds, because any deduction that can be made from the main and fore-rigging, as compared to a brig's of the same tonnage, is not quite sufficient for the support of the mizen-mast. Accordingly, I find it necessary to add 1-8th part of the tonnage to the momentum for the squares of the lower rigging, a brig's being twice the number of the register tons the ship's is—$2\frac{1}{8}$, which is also the mean proportion found from comparing the strength of the shrouds of a number of ship-rigged vessels, as illustrated by the table.

Accordingly, *for the Dimensions of the Lower Rigging of a Ship,—Rule.* Take $2\frac{1}{8}$ times the number of her register tons for the momentum of the squares of the shrouds on one side, from which subtract 1-7th for the momentum of the mizen-shrouds, the remainder being that of the main and fore shrouds; these being divided by the intended number on each mast, the square root of the quotient is their girth respectively.

Example.—Suppose a ship of 300 tons register to have 11 shrouds on the fore-mast and main-mast, and 4 on the mizen; required, the girth of the shrouds?—Then $300 \times 2\frac{1}{8} = 637$, and $637 \div 7 = 90$, the square of the mizen-shrouds; and $637 - 90 = 546 =$ the squares of the main and fore-shrouds. Now $546 \div 11 = 49$, and $\sqrt{49} = 7$ inches for the girth of the shrouds on the main and fore-masts; also $90 \div 4 = 22.2$, and $\sqrt{22} = 4\frac{5}{8}$ inches for the girth of the mizen-shrouds.

N. B.—I have considered $2\frac{1}{8}$ times the register to be sufficient for common or ordinary quality of rope; but with the best quality, take $2\frac{1}{10}$ or $2\frac{1}{12}$ the register for large vessels. When very good rope, 2 times the register may be sufficient, but never less.

The square of the girth of the Main-stay is 1-3d of the register tonnage—the Fore-stay 3-8ths—the Mizen-stay 1-8th—the Main-Topmast-stay 1-6th—the Fore-topmast-stay 1-5th—the Mizen-topmast-stay 1-18th of ditto.

To find the girths of the above ropes, divide their momentum by the intended number, and the square root of the quotient is the girth required.

The Main-topmast-shrouds 1-3d of the tons per register—Fore-topmast-shrouds 1-3d—Mizen-topmast-shrouds 1-7th of ditto—the Fore-topmast Back-stays 2-11ths of the register tonnage—the Main-topmast Back-stays 2-11ths—the Mizen-topmast Back-stays 1-18th—the Bob-stays 1-3d.

All these dimensions are the squares of the girths; consequently, to obtain their girths, their square roots must be extracted, which may be very cleverly done by the table of squares and cubes before referred to, page 66.

The following Table shews the method of classing the different ropes of a ship of 400 tons register:—

Names of the Ropes—Momentum $400 \times 2\frac{1}{8} = 850$.	Parts of the Register Tonnage.	Squares.	Number of the Shrouds.	Squares of each.	Roots or Girths.
Fore and Main Shrouds, after subtracting 1-7th from momen.		729.4	11	66.3	$8\frac{1}{6}$ in.
Mizen Shrouds, 1-7th of the momentum............................		121.3	4	30.3	$5\frac{1}{2}$
Fore and Main Topmast Shrouds....................................	$\frac{1}{3}$	133.3	8	17.0	$4\frac{1}{16}$
Mizen Topmast Shrouds..	$\frac{1}{7}$	57	4	14.1	$3\frac{3}{4}$
Fore and Main Topmast Back-stays.................................	$\frac{2}{11}$	72.7	2	40.0	6
Or they may be made equal to 1-5th of the tonnage.......	$\frac{1}{5}$	80.0	2	36.3	$6\frac{1}{16}$
The Mizen Topmast Back-stay......................................	$\frac{1}{18}$	22.2	1		$4\frac{7}{8}$
Fore Topmast Stay and Spring-stay................................	$\frac{1}{5}$	80.0			
Stay..				45.4	$6\frac{3}{4}$
Spring-stay................................				35	$5\frac{7}{8}$
Main Topmast Stay and Spring-stay................................	$\frac{1}{6}$	66.6	2		
Stay..				38	$6\frac{1}{8}$
Spring-stay................................				28	$5\frac{3}{8}$
Mizen Topmast Stay..	$\frac{1}{18}$	22.2	1		$4\frac{7}{8}$

And so on for the other Ropes.

Although the preceding rules for the dimensions of the standing rigging may in general be considered quite sufficient for proportioning the strength of the shrouds, stays, &c. of all the different classes of merchant vessels, yet being anxious to establish the most correct and certain rules for this purpose, I have been induced to consider the subject still farther; for in this case, as in proportioning the masts, we must consider that merchant vessels measuring the same tonnage may be found to differ considerably in their proportions of length, breadth, and depth; and therefore the tonnage, although the most convenient data from which to proportion the rigging, cannot be the most perfect. The stability, in proportion to the tonnage, is very irregularly increased, depending entirely upon the proportions of the vessel. Those that have the greatest breadth in proportion to their length, have the most stability in proportion to their tonnage. Therefore I shall add the following rules for the dimensions of the shrouds of the three classes of vessels, viz. Ships, Brigs, and Smacks or Sloops.

1*st, For the Dimensions of the Shrouds for a Ship or three-masted vessel.—Rule.* To one and a half times the register tonnage of the vessel, add one and a half the length of her load-water line, also twice the extreme breadth in feet and inches, and the sum

is the momentum of the squares of all the lower-shrouds on one side; take 1-7th of it for the sum of the squares of the mizen-shrouds, and proceed in finding the girths as before directed.

2d, For the Momentum and Girths of the Shrouds for a Brig.—Rule. To one and a half times the tonnage, add the length and twice the extreme breadth of the vessel in feet and inches, and the sum is the squares of the girths of all the lower-shrouds on one side, which being divided, as before directed, by the number of shrouds, the square root of the quotient is the girth required.

3d, For the Momentum and Girths of the Shrouds for a Smack.—Rule. To one and a half times the tonnage, add one and a half times her length and extreme breadth in feet and inches; divide the sum by the number of shrouds, including the tackle-pendant, and the square root of the quotient is the girth required.

Note.—If this should be considered rather strong, and light rigging be required; to one and a half times the tonnage add the length of the load-water line and the breadth of the beam for the momentum, and proceed as before directed.

Having now brought our observations on the principles of masting and proportions of the rigging to a finish, it may be remarked, that although the rules which have been deduced and laid down for calculating the dimensions of the masts and rigging may not exactly coincide with the views of every experienced mariner, yet relying on the soundness of the principles by which we have been chiefly guided, they are here recommended, and may be acted upon with confidence.

Weight of Anchors and Cables.

The Anchors and Cables are a particular part of the outfit of every sea-going vessel, and their proper weight and qualities is an object of the greatest importance, as it frequently happens that the safety of the ship and crew must depend entirely upon them in times of the greatest danger. Their weight and strength should be in such a proportion to the vessel, as not only to hold her in the worst of weather, but also to stop her when in the act of driving by the force of the wind, waves, and current.

In the first case, when a vessel is to be kept in the same place where she is brought up, or intended to stop (if the weather is moderate), there is but little strain upon the anchor, the ship being laid nearly in a state of rest by the position and action of the sails; but in other situations, as when the vessel is driving with a strong tide, or with the force of the wind, waves, or current, towards a lee-shore, and requires to be checked or completely stopped by the power of the anchor and cable only, they will then have to resist a strain or shock, in proportion to the weight of the vessel multiplied by her velocity, adding the force of the wind acting upon the parts exposed to it. This will produce the greatest strain to which the anchors and cables are subjected; for when any vessel is once stopped, the strain upon the anchor is then only in proportion to the area of that part of the midship-frames which is immersed, diminished by the tapering of the bow, adding the strength of the current and action of the wind on the parts exposed. At all events, the anchors and cables should be in such a proportion to the vessel,

as to bring her up in any situation under every circumstance; yet at the same time they should not be too ponderous for being managed with the necessary complement of men which are requisite for performing the other duties in navigating the vessel.

I have never seen any proper rule for calculating the weight of anchors in proportion to the magnitude of the vessel, their dimensions for any particular ship being generally estimated by the weight of the anchors of vessels of about the same tonnage; and no regular proportion is followed. As ships differ very much in their construction, and commanders equally so in opinion respecting the weight of anchors, we find that many vessels are fitted with anchors much above or below their requisite weight, in proportion to the dimensions or construction of the ship; also vessels of the same tonnage and general dimensions may require a considerable difference in the weight of their anchors, according to the form of their bow and quarters, or buttocks.

In order to obtain a suitable dimension, and remove every inconvenience as far as possible, I have adopted the following rule, which has been deduced from the tonnage, length, breadth, and depth of a number of ships, and found to produce a good medium for all merchant vessels of from 20 to 700 tons on the common construction, and from which the following Table of Anchors has been calculated. But for ships which have a very full bow, and a high lean quarter, it will be necessary to add a little to the weight, as these vessels are found to ride much heavier than ships that have their bow and quarters justly proportioned; on the contrary, when the bow is thin and the buttock full, a small deduction of weight may be made with safety.

As the anchors with wooden stocks and hempen cables have been longest in use, and are best understood by masters in general (all other kinds of moorings having only been used as substitutes), I shall give the following rule for finding the weight of the anchors for wooden stocks, in proportion to the ship:—*Rule.* To $1\frac{1}{2}$ times the number of tons per register, add half the ship's length per register, half the extreme breadth, and half the depth of the hold from the main-deck to the keel; divide the sum by 34, and the quotient will be the weight of the anchor in cwts. qrs. and lbs.

Example.—Suppose a ship's length to be 91 ft. 9 in. breadth 26 · 4, depth 17 · 6, and measurement $280\frac{16}{94}$ tons—Thus, $1\frac{1}{2}$ times the tons = 420 ft. 3 in. + $\frac{1}{2}$ the length, 45 · 10 + $\frac{1}{2}$ the breadth, 13 · 2 + $\frac{1}{2}$ the depth, 8 · 9 = 488 ft. ÷ 34 = 14 cwt. 1 qr. 14 lbs., the weight of the anchor.

N.B.—When it is for an iron stock, divide by $28\frac{1}{2}$, or what is much the same, add 1-5th of the weight of the anchor, as found above, for the weight of the anchor and stock.

To find the girth of Hempen Cables, in proportion to the Anchors.—Bring the weight of the wood-stock anchor into lbs., and the cube root of once and a half the number of lbs. is the girth of the cable in inches and eighth parts of an inch.

When you have the girth of the cable, and it is required to find the weight of the anchor, cube the girth of the cable in inches and eighth parts, and 2-3ds of the cube is the weight of the anchor in lbs.

To find the Diameter of the Chain, in proportion to the Rope-Cable.—Rule. Take $1\frac{1}{2}$ times the girth of the cable in inches and parts, and the number of inches will be the diameter of the chain in 16ths of an inch.

Diameter of Chain substituted for small Ropes, and ACRAMAN'S *Average Proof-strain on the Chains.*

Girth of Rope. Inches.	Diameter of Chain. Inches.	Proof-strain with cross-bars. Tons.	Proof-strain without cross-bars. Tons. Cwt.
2	$\frac{5}{16}$	1	0 15
3	$\frac{6}{16}$	1	0 18
4	$\frac{3}{8}$	2	1 15
$4\frac{3}{4}$	$\frac{7}{16}$	3	2 15

Note.—The diameter of chain substituted for larger ropes or cables, also the proof-strain, will be found in their respective columns in the following table.

TABLE of DIMENSIONS *of* ANCHORS *and* CABLES *in Proportion to the Ship.*

Ship's Tonnage.	Anchors with Wood Stock and Hemp Cable.			Anchors with Iron Stock and Hemp Cable.			Girth of Cable.	Anchors for Wood Stock and Chain Cable.			Anchors for Iron Stock and Chain Cable.			Diameter of Chain.	Weight per Fathom.	Acraman's average Proof Strain,	
																With Cross Bars.	Without Cross Bars.
	Cwts.	Qrs.	Lbs.	Cwts.	Qrs.	Lbs.	Inches.	Cwts.	Qrs.	Lbs.	Cwts.	Qrs.	Lbs.	Inches.	Lbs.	Tons.	Tons.
10	1	0	4	1	0	27	$5\frac{3}{4}$	0	3	26	1	0	10	$\frac{9}{16}$	18	5	4
20	1	2	20	2	0	2	$6\frac{5}{8}$	1	2	11	1	3	15	$\frac{5}{8}$	25	6	5
30	2	0	22	2	2	15	$7\frac{1}{4}$	2	0	10	2	2	1	$\frac{11}{16}$	28	7.5	6
40	2	3	0	3	1	6	$7\frac{3}{4}$	2	2	13	3	1	5	$\frac{23}{32}$, or $\frac{3}{4}$	30	10	7.4
50	3	1	4	3	3	22	$8\frac{1}{8}$	3	0	14	3	3	0	$\frac{3}{4}$	33		
60	3	3	8	4	2	6	$8\frac{5}{8}$	3	2	16	4	1	12	$\frac{13}{16}$	38	11.10	8.8
70	4	1	10	5	0	23	9	4	0	14	4	3	22	$\frac{7}{8}$	45	13	9.16
80	4	3	8	5	3	4	$9\frac{3}{8}$	4	2	9	5	2	0	$\frac{7}{8}$	45		
90	5	1	4	6	1	10	$9\frac{5}{8}$	5	0	3	6	0	3	$\frac{29}{32}$	48		
100	5	3	6	6	3	24	$9\frac{7}{8}$	5	2	2	6	2	3	$\frac{15}{16}$	52	15	11
110	6	1	4	7	2	4	$10\frac{1}{8}$	5	3	25	7	0	19	$\frac{15}{16}$	52		
120	6	3	2	8	0	14	$10\frac{3}{8}$	6	1	21	7	2	25	1	59	18	14
130	7	0	26	8	2	20	$10\frac{5}{8}$	6	3	14	8	1	0	1	59		
140	7	2	24	9	1	1	$10\frac{7}{8}$	7	1	9	8	3	5	$1\frac{1}{16}$	64	22	
160	8	2	20	10	1	18	$11\frac{3}{8}$	8	1	0	9	3	17	$1\frac{1}{16}$	64		
180	9	2	18	11	2	10	$11\frac{3}{4}$	9	0	20	11	0	1	$1\frac{1}{8}$	72	26	
200	10	2	12	12	2	25	$12\frac{1}{8}$	10	0	9	12	0	11	$1\frac{1}{8}$	72		
220	11	2	5	13	3	11	$12\frac{1}{2}$	10	3	25	13	0	19	$1\frac{3}{16}$	79	29	
240	12	1	27	14	3	27	$12\frac{3}{4}$	11	3	13	14	0	27	$1\frac{3}{16}$	79		
260	13	1	21	16	0	14	$13\frac{1}{8}$	12	3	2	15	1	8	$1\frac{1}{4}$	88	32	
280	14	1	15	17	1	1	$13\frac{3}{8}$	13	2	14	16	1	11	$1\frac{1}{4}$	88		
300	15	1	8	18	1	15	$13\frac{3}{4}$	14	2	7	17	1	25	$1\frac{5}{16}$	98	35	
320	16	1	0	19	2	0	14	15	1	21	18	2	3	$1\frac{5}{16}$	98		
360	18	0	13	21	3	19	$14\frac{1}{2}$	17	0	24	20	2	17	$1\frac{3}{8}$	110	38	
400	20	0	0	24	0	0	15	19	0	0	22	3	5	$1\frac{13}{32}$	112		
440	21	3	9	26	0	22	$15\frac{1}{2}$	20	3	0	24	3	15	$1\frac{7}{16}$	115	41	
480	23	2	20	28	1	18	$15\frac{7}{8}$	22	2	0	27	0	0	$1\frac{1}{2}$	125	44	
500	24	2	11	29	2	2	$16\frac{1}{8}$	23	1	14	28	0	5	$1\frac{1}{2}$	125	44	
550	26	3	14	32	0	27	$16\frac{1}{2}$	25	2	4	30	2	16	$1\frac{9}{16}$	134	48	
600	29	0	15	34	3	23	$16\frac{7}{8}$	27	2	20	33	0	24	$1\frac{9}{16}$	134		
650	31	1	13	37	2	15	$17\frac{3}{8}$	29	3	6	35	3	1	$1\frac{5}{8}$	146	52	
700	33	2	10	40	1	6	$17\frac{3}{4}$	31	3	18	38	1	5	$1\frac{21}{32}$	150		
750	35	3	7	42	3	25	$18\frac{1}{8}$	34	0	3	40	3	9	$1\frac{11}{16}$	158		
800	38	0	5	45	2	17	$18\frac{1}{2}$	36	0	16	43	1	13	$1\frac{23}{32}$, or $\frac{3}{4}$	170		
900	42	1	18	50	3	16	$19\frac{1}{4}$	40	1	5	48	1	11	$1\frac{13}{16}$	176		
1000	46	2	20	56	0	1	$19\frac{7}{8}$	44	1	11	53	0	24	$1\frac{27}{32}$	184		
1100	50	3	10				$20\frac{3}{8}$							$1\frac{7}{8}$	195		
1200	54	3	15				21							$1\frac{15}{16}$	211		
1300	58	3	6				$21\frac{1}{2}$							2	230		

MARINE ARCHITECTURE.

PART IV.

TREATISE ON STEAM VESSELS.

VESSELS propelled by the power of steam-engines, generally called Steam-boats, are every year becoming more numerous, not only on the several coasts of Europe and America, but also in many of the most distant parts of the Globe. Their utility for the conveyance of passengers has exceeded the most sanguine expectations of the public.

While the steam-engine was but little known, and but very imperfect in its construction, several attempts were made to propel vessels by means of paddles turned round by the power of men or cattle, and some of these were by no means deficient in principle—a vessel of this description having crossed from Leith to Stockholm in Sweden. In 1737, Mr. Jonathan Hulls obtained a patent for a steam-boat, or a newly invented machine for towing vessels out of or into harbours, ports, or rivers, against wind or tide. In 1789, Mr. Symington launched a steam-boat on the Forth and Clyde Canal whose performance surprised every one present; notwithstanding which, she was laid up, on account of the damage which the motion of the water from the paddles caused to the banks of the canal.

After this period, Messrs. Bell and Fulton directed their attention to the subject, and by their ingenuity and perseverance brought the invention into complete operation. In 1800, Mr. Bell (as he informs us) applied to the late Lord Melville, to shew his Lordship the utility of applying the power of the steam-engine for propelling vessels against wind and tide; but the Admiralty, after a mature deliberation, were of opinion that the plan then proposed would be of no avail in promoting navigation. But being confident in his own mind of its advantages and practicability, and not receiving encouragement from his own countrymen, he made a correct prospectus and drawing of a steam-boat, and forwarded copies of the same to all the principal nations of Europe, and to the United States of America. In 1807, Mr. Fulton completed the first steam-boat in America; and in August, he started from the city of New York, and performed the voyage to Albany, a distance of 160 miles, in 32 hours, and back again in 30 hours, at a velocity of 5 miles per hour. After Mr. Bell's return from America,

he had a steam-boat built by Mr. Wood of Port-Glasgow, and in 1812 she was in full operation on the Clyde, which completely removed all doubts of the advantages of steam navigation.

Ungenerous as it may appear, it is a fact that the two individuals who had wasted their years and fortune in bringing this invention into practice, and to whom we are indebted for every advantage which results from steam navigation, were never rewarded. Although they never laid claim to the original idea, they are justly entitled to the full merit of the invention—a good design unexecuted being of little advantage either to the designer or the public.

The rapid increase of steam-vessels since their first introduction, is a manifest proof of their utility. The immense field for inland navigation on the lakes and rivers of America, and the interprising commercial spirit of the people of that country, are coincidents to which must be attributed the advancement which they possess over us in steam navigation. In 1822, there were upwards of 300 steam-vessels belonging to the United States of America, and in Britain about half that number. In 1827, the steam-boats in the former country was supposed to exceed 900, and in the United Kingdom and Colonies about 300, of which 72, making a tonnage of 8638 tons, were built in 1826.

In the early periods of steam navigation, the vessels were of small dimensions; but many of them are now built of very considerable magnitude, and by means of improvements on their construction, and on their machinery, their velocity is considerably increased, from 5 or 6, to 9, 10, or 11 miles per hour; and some farther increase may perhaps be attained.

The voyage from New York to Albany, which at first occupied 30 hours, is now performed in 15 or 15½; and that from New Orleans to Lousiville (on the Mississippi river), a distance of upwards of 1500 miles, is performed in eight days some hours, averaging eight miles per hour against the stream, the mean velocity of the up and down trips being about 12 or 13 miles per hour.

The voyage from London to Leith, a course of upwards of 460 miles, is now performed by the steam-vessels in about 50 hours, at the rate of 9 or 10 miles per hour. Some of our best constructed boats go at the rate of 10 or 11 miles per hour.

Few steam-vessels have as yet been chiefly employed in the carrying of goods, their principal design being for the conveyance of passengers; and in those situations where the inland navigation is most accommodating, they are found of the greatest utility. At the same time, it has been proved, that even on sea voyages of such distance as are not too great for the quantity of fuel that can be carried, they have excelled any class of sailing vessels with respect to the certainty of time in performing the voyage. Several of these vessels are not only fitted up for passengers, but also for carrying goods of every description. The steam-vessels between London and Leith have, as was expected from the success which had attended those on the west coasts, been well employed in the conveyance both of goods and passengers; and it is the general opinion of those who are aware of the efficacy of steam-packets, that at no very distant period the greatest part of the coasting trade will be carried on by these vessels.

Description of Plate XXIX.

Before giving their proportions, and the directions for their construction, I shall first give a general description of a steam-vessel of 80 horse-power, viz. the *Brilliant* (*Plate* XXIX. *Fig*. 1, *the Sheer-plan.*)

The principal difference of the construction consists in its great length, and the arrangements for the paddles and machinery. The other parts of the construction are similar to any common vessel, only having more rake of the stem, and being altogether of a sharper and finer form for fast sailing. In the sheer-plan, *a* is the centre of the paddle-shaft (the same parts are marked with the same letters in all the other plans and sections), *b b* the two main or paddle-beams, *d e f g h i j k l m n o* is called the wing-wale, which is mortised and tenoned to the ends of the beams, and secured to the same with wood or iron knees, as shewn on the deck-plan. The dotted line on the sheer-plan, marked *Load-water after plying* 3 *years*, shews the draft of water after she had been plying for that length of time, *i. e.* 8½ feet at the bow, and 9 feet at the stern, when ready to start, having a sufficient supply of coals, and 100 passengers on board, with all their luggage, &c.

Her draught of water, under the same circumstances, at the commencement of the first season of her plying between Leith and Aberdeen, was 7 feet 11 inches forward, and 8 feet 4 inches abaft; so that from the soaking of the bottom and the accumulation of mud, &c. between the floor-timbers, and the additional weight of various pieces that were added to steady and strengthen the engines, and the introduction of a heavier construction of boilers, her weight has been increased upwards of 40 or 50 tons, which is the weight of the additional quantity of water which she now displaces. It is of the utmost importance that the draught of water, when the vessel is finished, agree with that for which she has been calculated. If this is not the case, the paddles will in a short time be too far immersed for producing their best effect in propelling the vessel. As all vessels will accumulate in weight, and, after they have run for some time, draw more water than at first, their engines should be constructed so that their paddles may be raised to any required height, in the most convenient and least expensive manner. I consider 9 feet to be a very proper draught of water for a vessel of this size, if the nature of the harbours will allow it, as the vessel will be less leewardly and more effective in boisterous seas. This vessel drew 6 feet 3 inches water abaft, and 3 feet 10 inches forward, when launched, and 7 feet 3 inches abaft, and 6 feet 6½ inches forward, when finished, with *masts, rigging, cabins, chain-cables, anchors, engines*, and *boilers* on board, which was within one inch of her calculated draught of water. I have since taken equal pains in calculating the displacement of several steam-vessels, and with one exception, they, when built and fitted out, were very near the calculated depth of water. In the vessel alluded to, her draft of water, when launched, was correct; but the actual weight of the *engines, furniture*, &c. must have exceeded the estimate considerably, as she drew 4 inches more water than I expected. Fortunately, however, the engines, which were fitted up by a very able engineer, Mr. James Cook of Glasgow, were on such a principle that the paddles were raised with very little trouble.

On the sheer-plan of the vessel referred to (*Plate* XXIX.) the line *b s r p o, &c.* represents the rabbet of the fore-sponson, and *b t v w* the rabbet of the after-sponson, or plank with which the sides of the vessel are filled out towards the wing-wale. The sides of this vessel are carried along the same as any other sailing vessel, and the deck projects over at midships to half the projection of the paddle-box. Sometimes the deck is carried out the whole breadth of the paddle-box (as represented by *Figs.* 144 and 145, *Plate* VIII. at the end of this volume), when a great deal of room is wanted on deck, for carriage of cattle or passengers. Although by carrying the deck out in this manner, the paddle-beams are more easily steadied than when they only project out themselves, it is not generally approved of for sea-going boats; for in this case the sponson, which must be put on to keep the sea from washing up the deck, lies with a great inclination from the upright of the ship's side, and tends to make her roll to windward, by the sea lifting her on the sponson on the lee-side. On this account many of the large sea-going boats have no sponson beyond the side, and no projection of the beams, except the paddle-beams, and are finished and bound with knees the same as any common sailing vessel. Sometimes the side is carried out from the load-water line to the top, in form of a bell-flange, as represented by *Figs.* 150 and 151, *Plate* VIII. Although by this method a little more room is saved inside the vessel as at *c* (*Fig.* 151), yet as the part at *d* is often grain-cut, the side must be very weak; it is also difficult to fasten the ends of the beams to the sides of the vessel when they are thrown out in this manner. The best method, however, of securing and binding the beams to the side, and by which the paddle-beams are greatly supported, is to project the wing-wale to half the projection of the paddles, and secure them with stringers, shelf-pieces, and iron-knees, as represented by the deck plan, (*see Plate* XXIX.) The floor-plane presents nothing different from that of any common sailing vessel, except that in it the ribband and water-lines are much finer, the vessel being altogether upon a much sharper construction. The body-plan, also, is nearly the same as for any other vessel, and the midship-frame has little rising in the floor, on purpose to get the bedding for the engine-frame and sole-plate as low down as possible, and to keep the paddles clear when the vessel takes the ground.

The longitudinal section presents a view, supposing the vessel to be cut up the middle from stem to stern. Beginning first at the bow, *a b c d* is the head and cut-water, shewing the pieces of which it is built, the dotted lines being the bolts which fasten them together, and secure them to the stem; *c e f g* is the main-stem and cut-water, extending from *d*, down to the fore end of the keel; *h i j* are the apron pieces, *k k k* the breast-hooks, *l* the stemson, *m* dead-wood, *n n n* the floor-timbers, *o o o* the main-keel, *p p p* the keelson and height of the engine-bearers, *q q q* the dead-woods abaft, *r r r* the the dowals with which they are fastened, *s s* the stern-post, *t t t* the transoms, *u u u* the stern-timbers; *u* T M K I D A B the deck. The space A B C (*see also the Deck-plan*) is the forecastle, or cabin for the sailors; the space C under it is the fore peak appropriated for holding ropes, sails, &c.; A D E F G the fore-cabin or steerage, fitted up with seat-lockers all round; J J below it is the fore-hold for holding coals, &c.; Y a hold for goods, abaft which, to the extent I K = 35 feet, is the engine-room (this length

is deducted from the full length of the vessel in calculating the tonnage of steam-boats), in which is represented a plan and section of the engines and boilers, merely to assist the general description.

The Engines, each of 40-horse power, are fed from three boilers: A A is the centre one, B B the larboard-side one. (*See also the Deck-plan and semi-transverse section*, on which the same letters are marked on the same parts of the engines, &c.) The water is converted into steam by the heat of the fires in the flue C, which are conducted in a winding manner towards the chimney or funnel D, which is carried a considerable height above the deck, for the purpose of giving a draught to the furnaces. The boilers are filled with water to the level *u* V, and there is no communication for the water from the one boiler to the other. The steam, however, has a free communication from the one to the other by the pipe E, which at the same time is provided with a valve, that the steam may be shut off if thought necessary. In order to ascertain if the water is standing at a proper height in the boilers, they are each provided with two cranes, marked 8 and 9, the one a little above the line *u* V, and the other below it; so that when the water is at the proper height, if the upper one is opened steam will issue out, and also water from the lower one; but should steam issue from both, then there is too little water in the boilers—on the contrary, should water be emitted from the upper one, the reverse is the case. On the top of the centre boiler is placed an iron chest, containing a valve *e*, which opens upwards with a certain pressure; this is called the safety-valve. It is loaded so that its weight, added to the pressure of the atmosphere, will exceed that of the interior steam while under a proper strength; but as soon as the steam in the boilers increases so as to become dangerous, its pressure preponderates over the pressure of the atmosphere and weight of the safety-valve, and forcing the valve up, escapes up the pipe *f f* into the funnel; the danger is then removed for the time, and the valve will again close and prevent the entire escape of the steam. *g g* are the doors of the furnaces, F F the pipe which conveys the steam from the boiler to the valve-case G, from which it is admitted, at proper intervals, into the cylinder H, and acts alternately on the upper and under side of the piston. In the pipe F is placed the throttle-valve, for the purpose of shutting off the steam from the engine, or regulating the necessary quantity. In land-engines, this valve is opened or shut by the centrifugal force of two metal balls fixed on two jointed arms of an upright spindle, which is turned round by a belt from the main shaft of the engine.

The engine stands on a large flat plate of metal, which is bedded solidly down on the top of two solid logs of timber running fore-and-aft the vessel parallel to the kelson; these are called the engine-bearers, and must be very securely fitted and bolted to the floor-timbers of the vessel, as all the framing parts of the engine and the cylinder H are secured down to them. *h j* is the side of a strong cistern, passing through which is the axle *k*, on which is fitted the side or walking beams L L. G is called the valve-case, or steam-chest, through which there is an opening to both ends of the cylinder, and a communication to the condenser I. From the condenser there is a communication to the air-pump J, which also communicates with the cistern K, called the hot-well, and from which the pipe 10 (*see the Deck-plan*) communicates to the outside of the vessel;

this pipe is called the discharging or waste-water pipe. The pistons in the cylinder H, and air-pump J, being packed round with flax, are attached to their respective piston-rods, which pass up through the stuffing-boxes in the cylinder and air-pump covers; these are then screwed down to the flanges on the top of their respective cylinders. The piston-rod is turned perfectly cylindrical, and finely polished, to prevent any steam from escaping from the cylinder by its sides, or the admission of air when the vacuum is on the upper side of the piston. On the upper end of the piston-rod is fixed the cross-head (seen in the Ground-plan) marked 1 and 1′; to the extreme ends of the cross-head are attached the side-rods, marked 2 2′, the lower ends of which are attached to the walking-beam L L. M′ M′ are the standards or framing for supporting the paddle-shafts, on which are fixed the cranks N N (*see Ground-plan*); these are connected by a pin, which also passes through the upper end of the connection-rod O O′, which is connected to the ends of the walking-beams at the lower end P. The small pipe (seen on the ground-plan, and marked 3 3′, called the injection-pipe, is to admit cold water into the condenser I, to condense the steam when it has performed its office in the cylinder, all which condensed steam and water is drawn off from the condenser by the air-pump, from which it is driven into the hot-well, and thence discharged through the waste-water pipe, with the exception of such a quantity as may be required to keep up the supply of water in the boilers. The water is forced from the hot-well to the boilers through the small pipe marked 4 4′, by a force-pump, which is wrought by a piston attached to the end of the cross-head of the air-pump marked 5. The metal ball marked 7, acts by its weight as a counter-balance to the weight of the slide-valves in the valve-case G; these are slidden up and down to admit the steam alternately into the upper and lower ends of the cylinder, by a rod called the eccentric rod, which is connected to a circular hoop of metal, in the inside of which revolves an eccentric piece fitted on the paddle-shaft, and so pushes the rod backwards and forwards alternately.

Having thus shortly noticed the principal parts of the engine and boilers, some idea of the manner in which they are wrought, and the motion communicated to the paddles, may now be obtained. Suppose the steam to be admitted from the boilers through the pipe F, by opening the throttle-valve and the upper slide-valve in the steam-chest G, it will press on the top of the piston; then, from the connexion of the piston-rod to the cross-head, the side-rods will be pushed down, carrying with them the end of the walking-beam L, which is next the cylinder, and the other end with the connecting-rod O O′ will be raised up, and so turn the crank N upwards, and the paddle-wheel round. When the piston has reached its greatest descent, the steam which was employed to force it down is immediately drawn from the cylinder, and condensed into water in the condenser. At this instant the lower steam-valve will be open, and the steam will rush into the cylinder under the piston, and a vacuum being produced above it, will force up the piston, and so carry with it the end of the walking-beam, which before was pressed down. The lower eduction-pipe will now open to the condenser, and the steam will be again admitted to the top of the piston, under which a vacuum will be made, and the piston again descend; the connecting-rod to the crank

will again ascend, also the air-pump be raised up, and again they will descend upon the next stroke of the engine, and so continue ascending and descending alternately. The same opening and shutting of the valves taking place, a rotatory motion is thus communicated to the paddles to propel the vessel forward.

To return again to the cabins. The great cabin is included in the space K M N O K; Q P O is the seat or sofa; R R R the back of the sofas. In this cabin, the sofas are fitted up in such a manner as to form two heights of beds all round. The backs of the sofas, which are hinged to the ship's side, when folded up and supported by the pillars or pilasters form the upper tier of beds, the seat-lockers during the day forming the lower tier of beds at night. The bedding is stowed in the lockers when not required. From M to T is the staircase or lobby. In going from the deck into the cabin, you follow the figures 1, 2, 3, 4 (*see also the Deck-plan*); *y* is the door of the ladies' cabin, and B B the beds; C′ the captain's state-room, and B″ the bed. All the other parts, the steering-wheel, beams, hatches, &c. will be understood by inspection of the plate, and therefore any farther description is unnecessary.

General Proportions.

Steam-vessels may in general be divided into two distinct classes, whether for the conveyance of passengers or carriage of goods, viz. *River* and *Sea-going* vessels; a considerable difference, not only in their requisite strengths, but also in their general proportions or constructions, and propelling power, being absolutely necessary to render each most suitable for their respective trades, or the passages which they have to perform. I shall therefore, in the first place, state their best proportions of length, breadth, and depth, at least so far as I have known these two classes of vessels to answer their purposes; in the second place, give directions for constructing their plans; and in the third place, notice their power, with such other observations on the subject as may occur.

Proportions of Length, Breadth, and Depth.

In *River-boats*, the breadth of the hull, exclusive of the projection of the paddle-box, should not exceed 2-11ths of their length on the load-water line, nor be less than 1-6th of that length. The depth of hold, from deck to ceiling, should not exceed 5-9ths, or be less than one-half the breadth, as determined above.

In *Sea-going* vessels, the breadth of the hull, exclusive of the projection of the paddle-box) should not exceed 1-5th of their length on the load-water line, or be less than 2-11ths of the same; and their depth of hold, from deck to ceiling, about 3-5ths of the breadth at midships.

Now from these, it appears at once that steam-vessels differ very much in their proportions from sailing-vessels; the principal reason for which is, that by their being on a long narrow construction, a sufficient room and convenience is obtained for the passengers, &c. independent of the space for the engines and boilers; and being narrow, or of a good length, it allows them to be finely tapered towards the bow and stern, so that they may be the more easily propelled, and draw little water in proportion to their sharpness; they having

at the same time sufficient breadth to carry engines of such power as will propel them with the required degree of velocity, or with a greater degree of velocity than any vessel of this description has been known to pass through the water. Also at this proportion of breadth they will be found to have sufficient stability to enable them to carry a moderate quantity of sail, when rigged on a low construction. If, however, the breadth be much less than 2-11ths of their length, they become not only crank, but also much weaker, and more easily strained. The sea-going vessels in general require to have their breadth nearly 1-5th of their length on the water-line, to make them carry proper sails without heeling them too far over, which subjects the paddles to very unequal strains, and retards the motion of both the engines and the boat.

On the Dimensions and Proportions of the Materials, &c.

The whole frame of timber, stem, stern-post, &c. &c. for a steam-vessel, should be of the same scantling as that for any regular built merchant vessel of the same breadth. All the planks along midships 1-8th of an inch in thickness for every four feet of the length of the vessel; at the hoods 2-3ds or 3-4ths of the thickness in midships. The wales should be 1-4th thicker than the bottom plank, which is generally of Memel or Dantzic fir, if it can be obtained. The keels of all steam-vessels designed to ply in rivers, or places where there is but little depth of water, should be sided of a good breadth in midships, and made as thin or shallow as six or seven inches; but the pieces towards the stem and stern post should be from 12 to 18 inches deep, if it can be got, in order to answer for dead-wood, and part of the garboard-strake. The kelson should be 3-4ths of an inch square for every foot of the breadth of the vessel, exclusive of the paddles. The deck-beams should have a round-up of 3-8ths of an inch for every foot of their length. The engine-bearers, four in number, should be each as strong as the kelson, and extend past the engine-room fore-and-aft at least equal to half the ship's breadth, and with the kelson should be completely bolted, so that the vessel may not bend or twist during the whole length of the engine-room. The midship part of the vessel should be completely trussed between the timbers with pieces of sound hard oak, forming a parabolic arch from the bilge upwards, having its vertex a little below the centre of the paddle-shaft, or about that height, in the middle between the centre of gravity of the machinery and the centre of gravity of the whole vessel.

I have, at the end of the treatise on the strength of materials, prefixed a table of the comparative strength of timber, which is also calculated for the strength of paddle-beams, according to the power of the engines (*see page* 68) from those required for a boat of five-horse power up to one of 260; and have merely farther to observe, that all the other parts of the vessel may be completed in the same proportions as those of a common vessel of the same breadth, that is, in respect to *the beams, decks, weight of anchors, size of the windlass, cat-heads, &c.*

On Drawing the Moulding and Working Plans.

In commencing with the plan of a steam-boat, the tonnage and dimensions of length, breadth, depth, &c. must be first determined, according to the circumstances or trade for which she is intended, and proportioned agreeably to what we have already stated, *i. e.* for

river-boats the breadth between 2-11ths and 1-6th of their length, and for sea-going vessels, between 1-5th and 2-11ths, and their depth of hold as also stated above. The greatest possible care must be taken to give her such a form in the bottom as will be the most favourable for fast sailing on a moderate draught of water; also the displacement at the proposed depth of water must be very accurately calculated, and made to agree with a correct estimate of the whole height of the vessel, in order to fix on the height of the paddle-shaft and other arrangements of the engine work.

Those who have had little experience in building steam-boats will require to be very accurate in these operations, and duly consider every circumstance connected with these vessels, which differ considerably from the common merchant-ships.

In the first place, having made out a specification, and calculated the dimensions and weight of all the different materials, draw a sketch-plan of the intended vessel, and you will be able to ascertain more precisely the quantity of the oak and other timber required for the framing and planking of the vessel; also ascertain the weight of all the requisite iron fastenings, such as bolts, knees, &c.; then, by applying to the engine-maker, you will obtain an estimate of the weight of all the machinery, boilers, &c. the quantity of coal required for the intended passage, two thirds of which may be taken for the mean quantity; you must next estimate the weight of the masts, sails, rigging, anchors, cables, cabin and other furniture, stores, boats, &c., the weight of the average number of passengers, luggage, &c.; also add a small thing to the full weight thus found, for the soaking of the bottom.

Having obtained a fair estimate of what will be the ultimate weight of the vessel, including every thing, the plan must now be accurately drawn in nearly the following manner:—Draw lines for the upper and lower edge of the keel, perpendicular to which, in the middle of the paper, draw another for the centre of the ship's length, from which measure afore and abaft on the upper edge of the keel, the half length of the vessel, *i. e.* the length of the keel for tonnage, at which draw up perpendiculars to the keel, and set up the stem and stern-posts, the part of the stem above the load-water line with a rake of about 6 or 8 inches to the foot. The stern-post may either be placed upright, or have a small rake aft, which is preferable to having it quite upright. When it is intended to project the deck beyond the ship's side, care should be taken that the beams, by rounding down, do not throw the wing-wale and paddle-bearer down with a quick sheer about the middle of the vessel, which is the place of their greatest projection. To prevent this, draw a line as much above the regular sheer line of the ship's side as the beams round-down by their projection over the same, and make the frames that much higher than the intended sheer of the wing-wale. On the sheer-plan of *Plate* XXIX. I have marked this height or top line on the frames. Take the intended depth of water, and mark it up from the lower side of the keel, and at that height draw a line fore-and-aft to represent the load-water line. There can be no correct rule given for the height of the line of floatation in proportion to the dimension of the boat, particularly river-going ones, as this must always be regulated by the nature of the rivers in which they are intended to ply. As a general rule, however, for river-boats, their draft of water at the paddle-shaft should be about 1-4th of their breadth. In order that the boat may not exceed this proportion, she must be very flat on the bottom, and every excess or superfluous weight of materials must be rigidly rejected.

The draft of water of sea-going vessels, which do not enter shallow rivers or harbours, should be about 2-5ths of the breadth of their midship-frame. Having drawn the line of floatation to this height, next draw the other lines, wales, stern, counter, &c. in the same manner as with the plan of any common merchant-vessel. Draw the centre line of the floor-plane, and proceed to draw the main half-breadth line; to do which, let fall a perpendicular from the spot where the top-height line cuts the inside of the rabbet of the stem, to the centre line of the floor-plane, to give the ending of the main-breadth line. The position of the midship-frame, or *centre of the paddle-shaft*, which should be in the same place, must next be determined. The centre of the paddle-shaft should, if possible, be placed near the centre of gravity of the vessel, that the paddles may have little rising or falling with the pitching motion of the ship. As a general rule, multiply the length of the load-water line by .4, and set this distance aftwards from the rabbet of the stem on the load-water line, and it will mark the place of the *midship-frame* or *paddle-shaft*, in nearly the same proportion as the paddles of the *Brilliant steam-boat* (*Plate* XXIX.) are placed. Owing to the great length and flatness of the side, the main breadth may be kept nearly straight and parallel to the centre line, equal to the half breadth of the wheel on each side of the centre line of the paddle-shaft. To find a spot near the bow through which to draw the *main-breadth* line,—at half the breadth of the midship-frame from the rabbet of the stem, at the line squared down to the floor-plane, draw a line perpendicular to the centre line, from which set 7-19ths of the breadth of the midship-frame, and it will be a mark through which to draw the main or top-breadth line. Also, to find its breadth at the wing-transom, set 7-8ths of the breadth of the midship-frame from the centre line, and then with a sheer mould or regular bow, draw the main-breadth line, marked *M. B.*, reconciling with the half main-breadth at midships or paddle-shaft, gradually partaking of more curvature as it approaches the stem.

The next thing is to erect the midship-frame, and draw in the side-lines, diagonals, &c. &c. in the same manner as for any common vessel. The length of the midship-floor, for river-boats, may be 3-4ths of the breadth of the frame, and have a rising of about one-half inch for every foot of its length, which will make a very flat bottom, favourable for drawing little water, and also for allowing the engines to be placed low in the vessel, that the paddle-shaft and other parts of the machinery may, if possible, be kept below the deck. For sea-going boats, it will answer better to give them more rising of the floor, to prevent them from rolling as much as possible; they may therefore have one inch of rising for every foot of the length of their floor (*see Body-plan, Plate* XXIX.) which, from the second diagonal to the keel, may be drawn straight, or have a small inward hollow. The load-water line must be measured from the sheer, and drawn across the body-plan, which will give the lower height of breadth of the midship-frame, which may then be drawn as for any other common ship.

The *Load-water line* may now be sketched-in on the floor-plane. From the sheer-plan square down its termination at the rabbet of the stem and stern-posts to the floor-plane; and as the lower height of main breadth at ⊕ extends down to the load-water line, these two lines will coincide for a good part of the middle of the ship. To find a few spots in the after and fore body, through which to draw the load-water line—first, at half the

breadth of the midship-frame from its termination at the stem in the floor-plane, draw up the line *g h*, on which set 6-17ths, or 1-3d of the breadth of the midship-frame, and it will be a mark through which to draw the curve sufficiently sharp for a fine going steam-boat. From the termination of the load-water line at the stern-post in the floor-plane, set foward half the breadth of the midship-frame, at which draw the line *i j*, and on it mark from the centre line 5-17ths or 5-18ths of the breadth of the midship-frame, or make the breadth of the run at this place 7-8ths of the entrance at *g h*, (*see the Floor-plane*, *Plate* XXIX.) which will make the run at the load-water line sufficiently sharp. Another spot through which to draw the load-water line may be found, by drawing a transverse line in the floor-plane, at the distance of the breadth of the ⊕ frame from the termination of the load-water line at the post, and on it mark 4-9ths of the breadth of the frame. Then having all these spots through which to draw the load-water line, the dotted line marked *L. W. L.* is drawn round quite fair from stem to stern.

As a farther guide in forming the run and entrance, the principle before laid down for sailing vessels may here be applied (*see* p. 181), the angle of the *fore adjusting water-line* must not be less than 23 or 24 degrees, and that of the after one from 12 to 13 degrees. The fore adjusting water-line is marked *n m*, and the frame *o p*; the after adjusting line *q r*, and the frame *s t*.

The *Balance-frames* may be placed in the same manner as for a sailing vessel (*see* p. 180), and the rising line made equal at both. In river-boats, and such as are to be on a very small draft of water, the bottom between the balance-frames may be nearly straight; but when a moderate draft of water is allowed, it should have a round of 1-8th inch for every foot of the length between the balance-frames.

Having determined on the round of the bottom in the fore-and-aft direction, the rising line must next be drawn in the sheer-plan, as directed at page 187; and the lines to represent the joints of the frames, also the intersection of the rising line at each, transferred to the second diagonal line in the body-plan, in which the balance and all the other frames are to be drawn, and the ribband and water-lines run in the floor-plane, as before directed for completing the draught of any common vessel.

On the Buttocks.—All sea-going vessels, but more particularly steam-boats intended to ply in a sea-way, must have good full buttocks, to prevent them from scending aft.

The plan being thus far completed, the displacement of the bottom, up to the determined load-water line, must be calculated, and its weight compared with the estimated weight of the whole vessel when completed with every thing, and ready for sea. To do this, first measure the area of all the water-lines, by measuring their breadth, adding the angled thickness of the bottom plank to each, from the centre line of the floor-plane, on the lines which represent the frames, from the foremost to the aftermost square frames; add all these together, taking only half of the extreme ones; multiply the sum by the distance between the frames, and the product is the area of the water-line from the fore to the after square-frame. The part *b c a*, before the square-frame at the bow, may be thrown into a triangle; and to find its area, multiply the length of the side *a c* by half that of *a b*; also proceed with the part of the water-line abaft the after square-frame in the same manner, and add these areas to the former; double the sum, and it will be the area of the whole water-line section on both sides of the centre line of the ship. In the

same manner proceed to find the area of all the other water-line sections, also of the upper side of the keel; add every two together for mean areas; multiply by the distance between each, and add their sums together, and it will be the solidity of the bottom, exclusive of the keel, and that part of the stem, stern-post, and rudder, which is under the line of floatation; the solidity of which must next be found, and added to the above, for the total displacement of the vessel up to her intended load-water line, in cubic feet, which being divided by 35, will give the weight in tons.—By way of illustration to the above, I shall add the calculation for the displacement of the Brilliant.

TABLE of Calculated Displacement of the Steam-Boat BRILLIANT *(Plate XXIX.)*

	Surface in the After Body.	Surface in the Fore Body.	Mean of every 2 Water-Lines in After Body.	Mean of every 2 in Fore Body.	Multipliers, the distance between the Water-Lines.	Contents in Cubic Feet and Inches. After Body.	Fore Body.	Fore & After Bodies.
	Feet. In.	Ft. In.	Feet. In.	Ft. In.	Ft. In.	Feet. In.	Feet. In.	Feet. In.
Area of load-water line from stern-post to ⊕,	1245 3							
Area of load-water line from stem to ⊕,	. .	779 10	1180 10	. .	× 1 11 =	2263 3.2	. .	3487 11.10
	. .	. .	. .	734 10	× 1 8 =	. . .	1224 8.8	
Area of 4th water line from stern-post to ⊕,	1116 5							
Area of 4th water line from stem to ⊕,	. .	698 10	1034 5	. .	× 2 0 =	2068 10	. .	3370 6
	. .	. .	. .	650 10	× 2 0 =	. . .	1301 8	
Area of 3d water line from stern-post to ⊕,	952 6							
Area of 3d water line from stem to ⊕,	. .	611 10	901 3	. .	× 1 6 =	1351 10.6	. .	2189 6
	. .	. .	. .	558 5	× 1 6 =	. . .	837 7.6	
Area of 2d water line from stern-post to ⊕,	850 0							
Area of 2d water line from stem to ⊕,	. .	505 0	692 6	. .	× 1 4 =	934 4	. .	1466 0
	. .	. .	. .	407 0	× 1 4 =	. . .	542 8	
Area of 1st water line from stern-post to ⊕,	535 0							
Area of 1st water line from stem to ⊕,	. .	309 0	301 6	. .	× 1 2 =	351 9	. .	553 3
	. .	. .	. .	173 6	× 1 2 =	. . .	201 6	
Area of upper side of keel from stern-post to ⊕,	68 0							
Area of upper side of keel from stem to ⊕,		38 0						
					Total, =	6959 0.8	4108 2.2	11067 5.10
Solidity of the keel,						68 0	39 0	107 0
Solidity of the stern-post and rudder,						27 9	. .	27 9
Solidity of the stem and gripe,						. . .	12 6	12 6
Total,						7054 9.8	4159 8.2	11214 5.10

	Tons.	Cwts.	Qrs.	Lbs.
From the above, it appears that the displacement of the bottom abaft ⊕ is 7,054.9 feet, =	201	11	0	16
" " " " " " " before ⊕ is 4,159.8 feet, =	118	16	3	5
Weight of water displaced by the vessel when immersed to the line drawn on the plan, =	320	7	3	21

Having, as now directed, calculated the displacement, its weight must be compared with that of the vessel, and if these are found to be the same, or nearly so, it may be concluded that the vessel will float at the required depth of water. If, however, the

weight of the water displaced be less than that of the whole vessel, then she must be made fuller in the bottom, by swelling out the water-lines on the fore and after-bodies; on the reverse of this being the case, she may be made so much the sharper, and after this alteration, the solidity of the bottom must again be measured, and the displacement again compared with her total weight, until these are at last brought nearly to agree.

The line of the centre of gravity and displacement may next be calculated thus:— The centre of displacement, in respect to the length of the vessel, must be situated so that there is an equal weight or quantity of water displaced before and abaft it. It must therefore be abaft ⊕ frame.

	Tons.	Cwts.	Qrs.	Lbs.
The displacement of the after-body being	201	11	0	16
Ditto of the fore-body, ...	118	16	3	5
Excess of displacement of the after body,	82	14	1	9

which being divided by 2 = 41 . 7 . 0 . 16; this added to the fore-body displacement, and subtracted from the after, brings them equal. Then, if we find the length dimension of the solidity of the bottom at midships, the cubic feet of which being divided by 35, will give 41 tons 7 cwt. 0 qrs. 16 lbs., and at that distance draw a line perpendicular to the load-water line, it will pass through the centre of displacement and centre of gravity of the whole vessel, these two centres being always vertical to each other. Thus the line marked *e f* (*see the Sheer-plan, Plate* XXIX.) is 9 feet 6 inches abaft ⊕, and the solidity of the bottom contained between it and ⊕ is 1447.5, which divided by 35 = 41 tons, 7 cwt. 0 qrs. 16 lbs., consequently the centre of gravity and displacement must be situated in some part of that line, as marked on the plate. The centre of displacement may also be found, by taking the mean area of every two frames below the water line, and multiplying each by the distance between them for the solidity of the spaces between the frames, which must be next multiplied by the mean distance of each from the bow or stern-post, and the sum of the momenta, divided by the whole solidity, will give the distance of the centre of displacement from the end of the vessel; or the distance of the centre of gravity from a perpendicular at the stem or stern may be found in the same manner, *i. e.* by dividing the hull into sections, and multiplying the distance of the centre of gravity of each from one end by its weight; then, dividing the sum of the momenta by the sum of the weights, the quotient is the distance of the centre of gravity from the end of the vessel. The height of these two centres above the under side of the keel may be found in the same manner. Thus—

		Cubic Feet.		Mean Height above the Keel in Feet.		Momenta.
Solidity of Bottom between load and 4th water-line	=	3487.9	×	8	=	27903.2
Ditto ditto 4th and 3d water-lines	=	3370.5	×	6.4	=	21571.2
Ditto ditto 3d and 2d water-lines	=	2189.5	×	4.6	=	10071.7
Ditto ditto 2d and 1st water-line	=	1466.0	×	3.3	=	4837.8
Ditto ditto 1st water-line and the keel	=	553.3	×	2.0	=	1106.6
Ditto of the keel	=	107.0	×	0.5	=	53.5
Do. of the stern-post and rudder, under water	=	18.0	×	5.0	=	90.5
Do. of the stem and cut-water ditto	=	9.0	×	4.5	=	40.5
		Solidity = 11201.2				Mom. = 65674.5

And $65674.5 \div 11201. = 5$ feet 8 inches, the height of the centre of displacement above the lower side of the keel. Also the height of the centre of gravity (found by dividing the sum of the momentum of the weight of all the different parts of the vessel, engines, paddles, masts, anchors, passengers, &c. &c. by the sum of the weights) is 9 feet 3 inches, that is, about 4 inches above the line of floatation. With the centre of gravity so situated, the vessel will be sufficiently stiff to carry a considerable quantity of sail. In making experiments on the model of a steam-boat for the conveyance of cattle, I found that its centre of gravity was 9 inches above the surface of the water, which agreed exactly with the calculation. To prove if she would be sufficiently stiff for every purpose, I removed the proportional weights of the cattle, &c. from the middle or 'twixt decks, and placed them all on the main deck, which, as I calculated, raised her centre of gravity about one-sixth of her breadth above the load-water line. She was then put into the water, and to my astonishment, still possessed a considerable degree of stability.

Having noticed the method of finding the place of the centre of gravity of the vessel when at her loaded trim, as marked on the plan, (which, if found first for the hull, rigging, &c. will be of considerable advantage in placing the paddles, engine, and boilers, &c. to the greatest advantage), the paddles should be placed as near the centre of gravity of the vessel as possible. To attain this object, without putting her any farther down by the stern, I would recommend turning the engine end for end with the cylinder towards the bow, so that the centre of the paddle-shaft would then be exactly in the centre of gravity of the vessel, and also of the engine and boilers. I have always found that the fastest boats have their paddles very nearly in the middle of their length; say 1-16th or 1-15th before the middle of the load-water line.

General Remarks.

River-going Boats are generally built on a shallow-water construction, and of the lightest materials. Many of them are but very slightly put together, so much so, that they are not sufficient to withstand the working of the engines that are employed to propel them. At the same time, it is known that no engine, however well constructed, can work up to its full power when placed in a vessel that works or twists to such an extent, as many of these boats are known to do, when exposed to but very slight shocks of the sea or waves.

Sea-going Boats, on the contrary, are generally built of the best materials and workmanship. Many of them are built of a heavy scantling of timber, particularly in the bottom, well fastened and bound with stringers, iron-knees, &c. and filled up completely between the floors; they have strong keelsons, and engine-bearers all along in midships, to prevent their working in the way of the engine-room. As it is impossible to build any vessel so strong as to prevent her from working or straninig more or less by the sea, the framing parts of the engine should be very strong, and require no supports or fastenings to the deck-beams.

The midship part of the side, *i. e.* in the way of the paddles, should be perfectly up-

right from the load-water line upwards, as this form will admit the greatest breadth of paddles with the least projection of the wing-wale. The most proper breadth of the paddles, in proportion to that of the boat or power of the engines, has perhaps not yet been discovered, and are of various proportions in different boats, but in general should be about 1-3d of the breadth of the midship-frame, including the thickness of the outside plank or bends, so that the length of the float-boards will be from 3-10ths to 6-19ths of the same dimension. Some of the small boats have the breadth of their paddles nearly half the breadth of their midship-frames, which answers the purpose in smooth water, where the vessel has no rolling motion, as the float-boards take a good hold of the water, with a small immersion; but would not answer a sea-going vessel so well, for this reason, that when she was rolling, the wheel on the one side would be too much immersed in the water, and the other almost entirely out of it, alternately, according to the run of the sea, which would be very injurious to the machinery, particularly that of the main shaft, besides throwing a greater strain on the paddle-beams, the wing-wale, paddle-box, and all projecting parts being more liable to damage in the event of the vessel falling across the sea.

To prevent those accidents which frequently happen to sea-going vessels in gales of wind, I would certainly recommend the use of the sliding-keels, particularly one at the fore part of the vessel, at about 1-4th of the length of the load-water line from the stem. This would be of the greatest advantage to all vessels when exposed to the run of the waves in gales of wind at sea, without increasing their draft of water for taking harbours. It would take little room in the vessel, and could be made perfectly safe in form, as shewn in *Plate* XV. of which see the description.

In constructing these vessels, so that they may combine the greatest degree of safety, the cabin and steerage floors and bulkheads should be made very strong, and perfectly water-tight; so that in the event of the vessel receiving any partial damage, or springing a leak in the bottom, she may have sufficient buoyance to float up the weight of the machinery and every other article on board. At the same time it must be remarked, that in the event of the vessel getting ashore, or beating on a hard bank, this precaution cannot be depended on, because, by the straining and twisting of the boat, the bulkheads and floors will work more or less, and soon become leaky; but it may, in other circumstances, be the means of saving her from sinking.

N. B.—It should have been noticed at page 277, that in making the stern-frame, the inner-post is sometimes continued as high as the upper side of the wing-transom, and the heels of the stern-timbers running down to the next transom below it, are then bolted to the after side of the wing-transom; which method not only reduces the curve of the W T, but also affords a better fastening to the heels of the stern timbers.

Having noticed the proportions and dimensions of steam-packets, and given directions for constructing their working-plans, it may be observed, with respect to the actual building of these vessels, that the whole workmanship and materials should be of the very best description, and carried on in the same progressive manner, and the same precautions taken for making good, work as I have already laid down in the practical

part of this work, for the building and completing of common merchant-vessels. As the practice of shipbuilding has already been fully explained, it is unnecessary to recapitulate our former observations on this subject; however, it will be proper to notice such parts of the construction of steam-boats as differ from those of common sailing vessels, and these consist chiefly in the upper-works, and framings for supporting the paddles, deck-beams, wing-wales, &c.

I have already referred to a table of the dimensions of the paddle-beams for steam-boats, proportioned by the power of the engines. (*See* p. 68.) These are the principal beams, and before their dimensions can be determined, the power of the engines, in proportion to the size and construction of the vessel, must first be considered. The paddle-beams cannot be properly proportioned to the dimensions of the boat, as those of the same tonnage may require a greater or less power of engines, according to their different constructions and weight, their intended velocity, or the roughness of the passage they will have to ply.

Power of the Engines.

However much the engines may appear to differ in form, they are in general only different modifications of Watt's double-working condenser-engines (at least in the steam-boats in Britain), the Legislature having very wisely prohibited high-pressure engines from being used on board of steam-vessels.

In noticing the power of the engines, I hope that no lengthened or elaborate investigation of the subject will be expected. Before the steam-engine was brought to its present state of perfection, or applied so generally as it now is for almost every purpose, the power of horses was used in driving all kinds of heavy machinery, where water-engines could not be obtained, and manual force was insufficient; and experience soon discovered the relative value of manual and animal power—one horse being considered equivalent to the power of five or six men working 10 hours per day, but the former much greater when for a shorter period. In order to estimate the mean of horse power, engineers have endeavoured to find the maximum weight a horse is able to raise in a given time.

Desaguliers supposed a horse able to raise	27500 lbs.	one foot high	per minute.
Smeaton, - - - -	22916 "	ditto,	ditto.
Watt and Bolton, - - - -	32000 "	ditto,	ditto.

The mean of the three making it 27470 lbs. raised one foot high per minute. Watt and Bolton, however, in constructing their engines, allow a horse to draw 200 lbs. over a pulley, at the rate of 220 feet per minute, which gives $200 \times 220 = 44000$ lbs. raised one foot high per minute.

Now, in calculating the power of the steam-engine, we must first consider the pressure of the steam, and the main rate at which the piston travels in the cylinder. The pressure of the steam for low-pressure engines is commonly 15 lbs. per square inch, and deducting 1-3d for the friction of the machine, and the imperfect nature of the vacuum in the condenser, there remains an effective pressure of 10 lbs. on every square inch of the piston. Again, we find that when the length of stroke is 3 feet, the engine makes

about 30 double strokes per minute, and of course travels at the rate of $30 \times 6 = 180$ feet per minute.

When	4 ft. stroke,	it makes	24	strokes, and travels	at the	rate of	192 ft.	per min.
„	5	„	„	20	„	„	„	200	„
„	6	„	„	18	„	„	„	206	„
„	8	„	„	13	„	„	„	208	„

From the above, it appears that the piston travels at a mean rate of about two miles per hour. To find the power of the engine, multiply the area of the piston in inches by 10lbs., and that product by the number of feet it travels per minute, for the momentum, or number of lbs. it will rise one foot high per minute; and this divided by a horse power, which according to Watt and Bolton's calculation is 44,000 lbs., gives the power of the engine. In general, 33,000 lbs. raised one foot high per minute, is taken for the data or horse power. It is evident, however, from the principle on which the power of the engines of steam-boats acts on the paddles, and these on the water, that this estimate of the horse power of the engine is much less effective than the force of that animal in propelling the vessel through the water. Some late experiments on the power of horses and that of steam-engines to drag or track vessels in canals, have shewn this to be as 1 to 4 or 5, four horses being found able to track the boat as fast along as a 20-horse engine was able to propel her, which is easily accounted for, the distance between the centres of the shaft and the centre of the paddle-board being often about four times the length of the crank; in this case, the engine can only produce an effect of 1 to 4 in propelling the vessel.

Having shewn the quantity of force usually considered as a horse power, I shall next notice the proportional power of the engines to the size of the boat. Before this can be accurately determined for any particular vessel, the resistance, according to her form or degrees of sharpness, and the required velocity, would require to be exactly ascertained; but it will be unnecessary to lay down any rules for calculating the resistance, as these would be found too tedious for practical use.

River-going Boats have commonly engines of one horse power for every $2\frac{1}{2}$ tons of their register measurement, but these proportions are by no means regular, some boats having only one horse power for every three tons per register, while others again have one horse power for every two tons per register.

Sea-going Boats have about one horse power for every three tons per register, which is found sufficient, when the vessel is properly constructed for fast sailing; several have one horse power for every $2\frac{3}{4}$ tons; others again only one horse power for every four tons per register, which is too little power. Many of the American steam-vessels are said to have only one horse power for every $4\frac{1}{2}$ or 5 tons per register. In general, the river-going boats have much more power in proportion than sea-going ones, and the more so when we consider that they are generally built on a sharper and lighter construction, and ply mostly in smooth water, where the engines work more completely to their calculated power. The power of the engines is much diminished by the pitching and rolling motion in sea-going vessels, which causes an irregular rising of the steam; also by the action of the waves on the paddles. In consideration of all which, these vessels should

properly have more power in proportion than river boats, and the boat and engines should be much stronger in proportion; indeed they should have as much power as can possibly be allowed, so that they may be able to withstand the shocks of the waves, and be propelled with any required degree of velocity. The reason of giving the sea-going boats less power in proportion to their size than river boats, is with the view of requiring to carry as little fuel as possible to supply them during their voyage. When the power of the engines required for any proposed boat is known, the dimensions of her paddle-beams may then be found to suit any shape of timber, by referring to page 68. Thus, for a boat of 80-horse power, the dimensions of her paddle-beams at the gunwale, the breadth being 2-3ds of the depth, is $14\frac{1}{2}$ inches deep by $9\frac{5}{8}$ inches in breadth; but if a piece of English or African oak cannot conveniently be obtained to make them in this proportion, without waste of material or the like, they may be made 16 inches deep and 8 inches in breadth, or $12\frac{5}{8}$ inches square, as at each of these dimensions they will be of equal strengths.

N. B.—Although the size of beams specified in the table, page 68, is sufficient to carry the weight, I would recommend them to be a little stronger, when the materials can be obtained, as that will be the means of the beams lasting longer, and being less liable to shake or vibrate.

When the paddle-beams are sided and moulded, or filled up on their upper sides to the round of the deck, they are hoisted on board, and put across the vessel. The situation of the paddle-shaft being determined on the plan of the vessel, the paddle-beams are to be placed only a little wider than the diameter of the wheel, in order to make the wing-wale, or piece of timber which is fitted on to the ends of the beams for supporting the outer end of the paddle-shaft, short, and as strong as possible in proportion to its size. The strength of any piece of timber so placed being inversely as its length, when the beams are placed 4 or 6 feet farther apart than the diameter of the wheel, they must be made much heavier than would otherwise be required, to support the weight, and prevent the shaking of the outer end of the shaft.

It is a general practice to place the paddle-beams 4 or 6 feet wider than the diameter of the wheel, to allow the back-water to escape more freely from the paddles. This is perhaps necessary on very low shallow boats, but certainly not on sea-going ones, although it is often done under the same notion. But in place of being of any advantage, it not only renders the wing-wale very weak, and allows it to vibrate, but from being so placed, the water from the paddle-wheel is thrown with great force against the foreside of the after one, which retards the motion of the boat, as is clearly illustrated by *Fig.* 142, *Plate* VIII., B being the after-paddle beam, placed about 1-3d of the diameter of the wheel farther aft than necessary. *Fig.* 143 shews the advantage of placing the beam B nearer the wheel, by which the wing-wale will be much stronger, and the water thrown up by the paddles will completely miss it, or at most only be thrown up against its under side, and have no tendency to retard the boat. Without presuming on the province of the engineer, it may be mentioned that the height of the paddle-shaft is commonly placed about one-third of the diameter of the wheel above the water. The diameter of the wheel may be found by dividing the square root of

the diameter of the cylinder in inches by 3.5; and when the boat has two cylinders, add the squares of their diameters in inches together, take the square root of their sum, and divide the product by 3.5, which will give the diameters of the paddle-wheels in feet and inches. Thus suppose a boat with two engines of 100-horse power each, the diameter of the cylinders will be 53 inches; required, the diameter of the paddle-wheel?—Then $53^2 = 2809$, which multiplied by $2 = 5618$, the square root of which is 75, and $75 \div 3.5 = 21$ feet 8 inches for the diameter of the wheel, as required; *or*, multiply the diameter of the cylinder in inches by the length of stroke in inches, double the product for both engines, and divide by 3.5, as before, which will give the diameter of the wheel in feet and inches, a small thing larger than before, when the length of stroke exceeds the diameter of the cylinder. Given, a boat of 50-horse power, having two 25-horse engines, diameters of the cylinders 29.5 inches, and length of stroke 36 inches; required, the diameter of the paddles?—$29.5 \times 36 = 1062 \times 2 = 2124$, and $\sqrt{2124} = 46 \div 3.5 = 13$ feet 2 inches, the diameter.

Having found a general proportion for the diameter of the paddle-wheel, the beams are to be placed only about 1 foot wider than the diameter of the wheel, as found above, unless it is the intention of the engine-maker to have a very large wheel, because some approve of a large wheel to get clear of the back-water; others, again, think the wheel should not be too large, as it reduces the power of the engines, and thus renders the boat less effective in going against a head-wind and sea when the paddles are on the first motion, which is generally more approved of than having them on the second motion.

The paddle-beams being placed, the other beams of the deck should be sided 3-8ths of an inch for every foot of their length, moulded in the middle to the same proportion, and at the ends they may be moulded 2-3ds of the moulding in the middle. They should not be placed farther apart than 4 feet, except where a wider berth is required for hatches or the like. Before the beams can be placed, the situation and size of all the hatches for cabin-stairs, sky-lights, &c. hatches for the boilers, above the cylinders, and at the cranks of the paddle-shaft, must be duly considered and planned out to the best advantage on the deck-plan, and the beams placed in the vessel accordingly.

Having three or four boilers, in place of one or two large ones, as is commonly the case, is of great advantage in getting them easier put in or taken out to be repaired; for when only one or two boilers are used, all the midship part of the deck and beams must be left out until the boilers are put into the vessel, and the deck is then laid down and caulked, which, by having the boilers in three, and a hatch made in the middle of the deck equal to 1-3d of the breadth, may be all done before the boat is launched, at which time these long narrow vessels are very apt to strain and receive considerable injury; therefore it is necessary to have the decks laid, and the ship bound the fore-and-aft way before launching. Also, when the boilers are in two, they cannot be taken out to be repaired without cutting the deck right across at her fore and after ends, or lifting a considerable part of it from above the cabins or the like, as the boilers must be lifted perpendicularly up. All this lifting and relaying the deck is attended with a considerable expense; it is therefore better and more convenient to have three boilers,

so that the two side ones may be first lowered down the hatchway, and screwed towards each side of the vessel, and the middle one lowered down between them, so that when any repairs are required, it may be hoisted out, and the side ones repaired in the hold, which will effect a great saving of time and expense. The beams at the hatch must be in three pieces, the middle pieces being scarphed to the inner ends of the outside pieces, and fastened with screw bolts, as shewn by the deck-plan (*Plate* XXIX.) Also the beams should be supported from the two sides of the middle boiler with iron supports, to prevent them from flattening in the middle. The beams should, when the deck projects beyond the ship's side, be secured by stringers and shelf-pieces, as shewn by the semi-section (*Plate* XXIX.) A being the beam, C the inside shelf-piece, and D the outside shelf-piece; *e* a dowal, and *f* a key of hardwood drove in between the natch in the under side of the beam and the outside shelf-piece; *g* the wing-wale, *h* the sponson timber, and *j* the stanchion of the main-rail. They should also be bound to the wing-wale with iron knees, as shewn on the deck-plan. The main or paddle-beams should be well secured to the side with wood or iron knees, and also be well supported with strong iron knees and stays on their under side and down the outside of the vessel.

On the Paddle-Wheels.

The Paddles, one for each side of the vessel, are formed of two cast or wrought-iron wheels, having arms radiating from the centre, and projecting without the rim; against the arms the float-boards are screwed. These are commonly made of wood, in length nearly half the diameter of the wheel, and in breadth about 1-8th or 1-9th of the diameter of the wheel; when the wheel is large, 1-10th of its diameter will be sufficient breadth for the floats or paddle-boards. Their number also is regulated by the size of the wheel, being commonly placed about three feet apart; their plane is generally parallel to the shaft, and at right angles to the rim of the wheel. (*See Fig.* 152, *Plate* VIII. and the plans of the steam-boat, *Plate* XXIX.)

On account of the oblique manner in which the float-boards of the paddle enter the water, and also are raised up when leaving it, a very considerable loss of power of the engines is supposed to take place, particularly owing to the back-water which they throw up; however, this is much less than is generally supposed, and if the wheels be of a pretty large diameter, it cannot be shewn that any loss of the power of the engines is occasioned by this circumstance. Another disadvantage attending the paddle-wheels results from the unequal depths to which they are frequently immersed, when the waves are running high, or the wind acting strongly on one side of the boat, so as to heel her over so that the lee-paddle is completely smothered, being deeply immersed, while the other has little or no hold of the water. At this time the strain on the shaft and other parts of the machinery is very great and unequal; and the broader the paddle is, the greater will be the irregularity of the strain on them in a sea-way.

With respect to the back-water, it must be observed, that although a certain quantity is raised up with every float-board (say 3 inches deep all over the float, which for a boat with two 40-horse engines is 6 feet the length of the float × 2 feet the breadth =

12 feet × 3 inches = 3 cubic feet of water, × 12 the number of floats = 36 cubic feet × 28 the number of strokes per minute = 1008 cubic feet, which × 64 lbs. = 64512 lbs. × 3 feet, the height to which it is supposed to be raised = 193536 lbs. raised one foot high per minute, which divided by a horse power, 193536 ÷ 33000 = 5.8 horse power lost by the back-water on each paddle), amounting perhaps to 1-8th of the power, yet at the same time it tends to push the boat forward; because the gravity of the water, acting upon the floats while they are in the oblique position, tends not only to depress the vessel, but to push her forward; and when they enter the water, in the same manner, its reaction not only tends to lift the ship, but also to push her forward.

Many different schemes have been suggested to improve the paddles, or to produce a better method of propelling steam-boats; but, as was anticipated by all who properly understood the subject, they have all failed, and we have little reason to suppose that any thing better than the common paddle will be produced.

Description of the Plates.

Plate I. Methods of constructing plane scales, describing ellipses, &c.

II. Construction of parabolas, hyperbolas, cycloids, &c.

III. Method of laying off flat elliptical curves, &c.
For description of these plates, see Practical Geometry.

IV. Figures in illustration of the principles of mechanics and strength of timber.—See treatise on Mechanics, and Strength of Materials.

V. Figures in illustration of hydrostatics, hydraulics, and the stability of floating bodies.—See treatise on Hydrostatics and Hydraulics.

VI. Figures in illustration of the stability of ships and of the principal sections and lines used in the plan, &c.—See article Stability, page 125; rolling motion, page 141; and explanation of the lines used in the draught, page 166.

VII. Various figures in illustration of construction of the draught, &c.—See pages 233, 301, 311, 321, 197, 200.

VIII. Figures in illustration of the action and side-pressure of the sails, steam-boats, &c.—See side-pressure of the sails, page 344; also treatise on Steam-boats, page 380.

Note.—The above Plates are bound up at the end of this volume; the following are in the Portfolio which accompanies it.

IX. Plans, sections, &c. of a double-working Pump.—See page 101 for description.

X. Plans of the different timbers of a Ship, and the most approved methods of binding.—For a description of this plate, see pages 153, 283, 296.

XI. Plans of the windlass, capstan, winch, &c. with their latest improvements, &c.—See pages 302 to 310, and to 315.

XII. Plan of the first principles and outline of a draught shewing the method of balancing and forming the bottom by sweeps of the compasses.—See directions for drawing the moulding-plans, sections, &c. pages 176 to 193.

Note.—On the back of this plate is drawn a plan of all the necessary moulds and sweeps used in ship-draughting.

XIII. Plan of a Packet of 48 tons measurement, referred to in page 170.

XIV. Plan of a Schooner of 104 tons measurement, drawn in a plan and section of one of the locks of the Forth and Clyde Canal, shewing the largest vessel that can pass through said canal. The sheer-plan is drawn in a longitudinal section, and the deck-plan in the ground-plan of the locks.

XV. Plan of a Schooner of $104\frac{78}{94}$ tons measurement, for the deep-sea fishery; also calculated for going through the Forth and Clyde Canal, and fitted with two sliding keels.

The sliding-keels were invented by Captain Shanks, and first used by him on the lakes of America; afterwards several small vessels were built and fitted with them for the British Navy. I had the first design of this excellent invention from Captain Shanks, who was then one of the Commissioners of the Navy; he also gave me an order to survey all the vessels fitted on this principle, and acquaint him of any improvements which I thought might render them more complete. I accordingly proposed to

him the introduction of two rollers, one on the upper part of the fore edge of the sliding-keel, and another about the middle of its after edge, and to have one winch to heave them up or down, in place of two which he had for that purpose—one to heave them up and another to depress them; but this was easily done, although the vessel might be going very fast through the water, by means of one winch and the rollers, which reduced the friction of the sliders considerably. To these improvements he freely assented, and on this principle I built and fitted out the Charlotte schooner (*Plate* XIV.) which answered the purpose very well.

The sliding-keels or vanes, in form of a large flat board, are made of strong pla ks bolted together edge-ways; they are made to slide up and down through the keel, kelson, and a water-tight trunk which extends up to the deck. They answer the purpose of lee-boards, and by taking a good hold of the water when fully down, prevent the vessel from going to leeward. There are generally two of them, one near the bow and the other towards the stern, as shewn on the sheer-plan (*Plate* XV.) H H being the keels.

The advantages which they confer on the vessel are—1*st*, When let down, they prevent her from going to leeward, and thus render a very flat vessel as weatherly as one on a sharp construction, and perhaps drawing 3 or 4 feet more water.

2*d*, In the event of the loss of masts or bowsprit, the fore or after keel may either be raised or lowered, so as to make the vessel work and balance the canvas, and thus preserve the steering trim.

3*d*, In scudding in heavy gales of wind and waves, they are of the utmost importance, for if the fore keel be hove up, and the after one lowered down to any convenient depth, the vessel may then be steered to the greatest nicety without the smallest risk of broaching-to.

4*th*, By means of the sliding-keels, a vessel may be stayed or wared under any sail; for by heaving up the after one, she will immediately come head to wind; then as soon as any of the head-sails takes a-back, by raising up the fore one, and lowering the after one a little, she will pay off as far as required; and when the sails are full, the fore one may again be lowered down, and the vessel steered to her proper course, which she will then hold with very little lee-way.

5*th*, In the event of losing the rudder, the vessel may be steered and held to her proper course by the position of the sails, and management of the keels.

6*th*, In the event of heaving-to, this may be done with safety under almost any sail, for by lowering the fore keel one half or two thirds down, and keeping the after one up, the vessel will immediately come head to wind, and may be laid in the most favourable position, without the least danger of her falling off. The *Charlotte* schooner was laid-to for nearly a whole week during a heavy gale in the North Sea, by means of the fore keel being lowered two thirds down, their sails being much destroyed before they thought of lying-to by the fore keel. During this time, in a most tremendous sea, she lay quite easy, and they were enabled to get all their sails repaired again.

These are a few of the advantages of the sliding-keels, and they are certainly worthy of the attention of shipowners who have vessels that are employed in those trades where a small draft of water is a desirable object.

The vessel represented by *Plate* XV. was drawn for the deep-sea fishery, on a shallow draft of water, and fitted with the sliding-keels, that she might sail well, and be hove-to on the fishing-banks.

The breadth of the keels, or their length the fore-and-aft way, should be each from 1-13th to 1-12th of the length of the vessel; and their depth under the main-keel, when full down, about 7-8ths of their breadth. The thickness of the plank of which they are formed should be 1-6th of the ship's breadth, taking inches for feet.

Fig. 1 (*Plate* XV.) is a section of the vessel at frame 10; A is the main keel, C C the timbers, E E the kelson, G G the planking of the well, J the standards of the winch, I the winch, and H the edge of the sliding-keel.

Fig. 2 is the longitudinal section, shewing the slider H, half down; A A the main-keel, C C the timbers, E E kelson, F F two strong standards or stanchions stepped into the kelson for supporting the planking of the well and the fore and after edges of the slider; N a clasp bolted to the upper end of the slider, to which the end of the rope or chain for drawing it up is fixed; L a stanchion fixed in the well or trunk, with a sheve M in its lower end, round which the rope passes for heaving down the slider when the vessel is sailing through the water; J the standards; I the winch round which the rope or chain is taken, and both ends being made fast at N, the winch, by being hove first the one way and then the other, will either raise or depress the keel at pleasure, which is my improvement on Captain Shanks' method of having two winches for that purpose. The stanchion L is slipped down through a grove of half an inch deep, which is cut in each side of the well, to keep it from moving or working the fore-and-aft way, and the stanchion is secured from rising, by means of its having a stout bolt put through its upper end and the sides of the well above deck, as shewn on the plan.

Fig. 4. A A is the main-keel, in breadth equal to 3½ times the wideness of the opening D for the slider. The dotted lines marked G G represents a groove of 3-4ths of an inch wide, and 1½ inch deep, passing all round the opening D, and under the floors at F and F. The feather for this groove is cut off from dry fir deal the cross way; these feathers are set up in the groove's end longways, and served over with white-lead; the keel is then prepared for fitting on the floor-timbers and the cheek-pieces marked B B, *Fig.* 3, in which A A is the main-keel, and C C the floors. The under side of the cheek-piece B, and floor-timbers at the two ends of the well D, are grooved, as represented by the dotted lines G G, to receive the upper part of the feather; the cheek-pieces and floors are then put on, being fitted at the ends to the floors, white lead being put all round the feather, and into the groove, to make them perfectly water-tight; the cheek-pieces are then bolted firmly to the main-keel, and the half floors dovetailed into them, as shewn on the plan, *Figs.* 1 and 3. A stop-water treenail is next drove down at the ends of the grooves of the cheek-pieces between them and the floors, to render the opening completely water-tight. The kelson is next put down, and the opening for the slider marked and cut out fair through; the kelson must fit very close down to the cheek-pieces and the floors at the ends of the opening, and be grooved and feathered in the same manner as the under sides of the cheek-pieces are done to the main-keel. Then, again,

on the upper part of the kelson, the standards and side-planks of the well must be neatly fitted, grooved, and feathered in the same manner, as shewn by the section, *Fig.* 1. The sides of the well or trunk are not fixed to the beams, but are merely made tight by nailing a strip of tarred canvas all round in form of a coat. The standards are fixed down to the kelson and floors by two strong iron knees on each. The sliding-keels are in form as shewn by *Figs.* 1 and 2. The rollers which run against the standards F and F′ are fixed at the top in the fore edge of the slider, and the other in the after edge, as far down as not to come below the opening when the slider is full down. The rollers project about 3-8ths of an inch, and may run on metal plates in the standards F and F. (On inspecting *Fig.* 2, I see I have neglected to draw the rollers on the slider H.) In bolting the planks together to make the sliders, the bolts must be small, and only put through two planks at once; and there must be as few as possible in the way of the opening of the keel when the slider is let down, in order that it may possess the whole strength of the planks if possible.

Plate XVI. Is a plan of a Schooner in the Leith and Hamburgh trade, measuring exactly $151\frac{70}{94}$ tons.

XVII. Moulding-plans of one of the London and Leith Smacks.

XVIII. Plans of a Brig of $203\frac{81}{94}$ tons.

XIX. Plans or draughts for a fast-sailing Brig or Yacht of $223\frac{64}{94}$ tons.

XX. Moulding-plans of a Brig of $303\frac{48}{94}$ tons.

XXI. Plan of the expansion of the bottom and top sides of Brig of 303 tons.—This plate is referred to at page 219.

XXII. Plans of a Ship of $347\frac{74}{94}$ tons, finished with head and quarter-galleries.

XXIII. Plans of a Ship of 400 tons, finished with full figure-head and quarter-galleries.—This plate is referred to in the directions for constructing the moulding-plans, see pages 183, 198, 201, 212, 214, 215, 216, 230.

XXIV. Plans of a Ship of 500 tons.—This plate is referred to in the work, and contains the plans of a ship of 500 tons measurement, calculated for the East-India trade.

XXV. Is the mast and rigging-plan of the Smack of 174 tons.—For the method of calculating the centre of effort, see page 350; for the principal spars, see page 363; and for the size of the standing-rigging, see page 374.

XXVI. Mast and rigging-plan of the Schooner, the moulding-plan of which is given at *Plate* XVI.—For the rules for calculating the masts and spars for a schooner, see page 361.

XXVII. Mast and rigging-plan of the Ship of 500 tons.—For the rules for calculating the dimensions of the masts and spars of ships, see page 351; and for the standing-rigging of ships, see page 369.

XXIX. Plans and sections of a Steam-boat of 80-horse power.—For a full description of this plate, see Treatise on Steam-boats.

FINIS.

INDEX.

CORDAGE TABLE,

Shewing how many Fathoms, Feet, and Inches, of Ropes of different Girths, from* 1 *to* $18\frac{3}{4}$ *inches, are required to weigh One Hundred Weight.

Girth in Inches.	Length of Rope.			Girth in Inches.	Length of Rope.			Girth in Inches.	Length of Rope.		
	Fathoms.	Feet.	Inches.		Fathoms.	Feet.	Inches.		Fathoms.	Feet.	Inches.
1	486	0	0	7	9	5	6	13	2	5	3
$\frac{1}{4}$	313	3	0	$\frac{1}{4}$	9	1	0	$\frac{1}{4}$	2	4	8
$\frac{1}{2}$	216	3	0	$\frac{1}{2}$	8	4	0	$\frac{1}{2}$	2	4	0
$\frac{3}{4}$	159	3	0	$\frac{3}{4}$	8	0	0	$\frac{3}{4}$	2	3	6
2	121	3	0	8	7	3	4	14	2	2	10
$\frac{1}{4}$	96	2	0	$\frac{1}{4}$	7	0	9	$\frac{1}{4}$	2	2	4
$\frac{1}{2}$	77	3	0	$\frac{1}{2}$	6	4	6	$\frac{1}{2}$	2	1	11
$\frac{3}{4}$	65	4	0	$\frac{3}{4}$	6	2	1	$\frac{3}{4}$	2	1	5
3	54	0	0	9	6	0	0	15	2	0	11
$\frac{1}{4}$	45	5	2	$\frac{1}{4}$	5	4	1	$\frac{1}{4}$	2	0	6
$\frac{1}{2}$	39	3	0	$\frac{1}{2}$	5	2	0	$\frac{1}{2}$	2	0	1
$\frac{3}{4}$	34	3	9	$\frac{3}{4}$	5	0	7	$\frac{3}{4}$	1	5	9
4	30	2	3	10	4	5	1	16	1	5	4
$\frac{1}{4}$	26	5	3	$\frac{1}{4}$	4	4	10	$\frac{1}{4}$	1	5	0
$\frac{1}{2}$	24	1	9	$\frac{1}{2}$	4	2	6	$\frac{1}{2}$	1	4	4
$\frac{3}{4}$	22	0	0	$\frac{3}{4}$	4	1	6	$\frac{3}{4}$	1	4	2
5	19	5	0	11	4	0	3	17	1	4	0
$\frac{1}{4}$	17	4	0	$\frac{1}{4}$	3	5	7	$\frac{1}{4}$	1	3	9
$\frac{1}{2}$	16	1	0	$\frac{1}{2}$	3	4	1	$\frac{1}{2}$	1	3	6
$\frac{3}{4}$	14	4	4	$\frac{3}{4}$	3	3	3	$\frac{3}{4}$	1	3	3
6	13	3	0	12	3	2	3	18	1	3	0
$\frac{1}{4}$	12	2	0	$\frac{1}{4}$	3	1	5	$\frac{1}{4}$	1	2	9
$\frac{1}{2}$	11	3	5	$\frac{1}{2}$	3	0	11	$\frac{1}{2}$	1	2	5
$\frac{3}{4}$	10	4	0	$\frac{3}{4}$	2	5	11	$\frac{3}{4}$	1	2	3

Note.—For the Rule for calculating the Table, see page 367.

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ARRANGED IN THE ORDER OF THEIR SUBSCRIPTIONS.

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——— John Duthie, shipbuilder.

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——— Robert Carsewell, ditto, ditto.
——— Joshua Muress, ditto, ditto.
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——— John Gray, shipbuilder.
——— James Goudie, foreman ditto.
James H. Robertson, Esq. banker.
Messrs. Robert Duncan, foreman shipbuilder.
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——— Joseph Pennell, sail-maker.

Messrs. Card and Co. brass-founders.
——— Macnab and Co. canvas-manufacturers.
——— Mathew Orr, sail-maker.

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——— Robert Turner, Lieutenant R. N.
——— Moshert.
——— George Renner, Master R. N.

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——— Robert Clark, ditto.
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——— Robert Reay, ditto, Hylton Place.
——— John M. Gales, ditto, Ford Lodge, Hylton.
——— Thomas Gales, ditto ditto ditto.
——— Geo. and W. Hall, do. Monkwearmouth.
——— William Potts, ditto, Sunderland.
——— Jas. Alison, ditto, Monkwearmouth shore.
——— George Mills, ditto ditto.
——— John Storey, ditto ditto.
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——— W. Adamson, shipbuilder, ditto.
——— W. Waters, shipowner, ditto.

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——— Arthur Gowans, shipbuilder, Berwick.
——— Bailey, shipbuilder, Ipswich.
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——— Jas. Adamson, shipbuilder, Grangemouth.
——— Robert Thomson, ditto, Troon.
——— James Bremner, ditto, Wick.
——— John M'Pherson, mariner.
——— Andrew Turnbull, engineer.
——— Brown and Scott, shipbuilders, Montrose.
——— Miller, shipbuilder, Limekilns.

PLATE I.

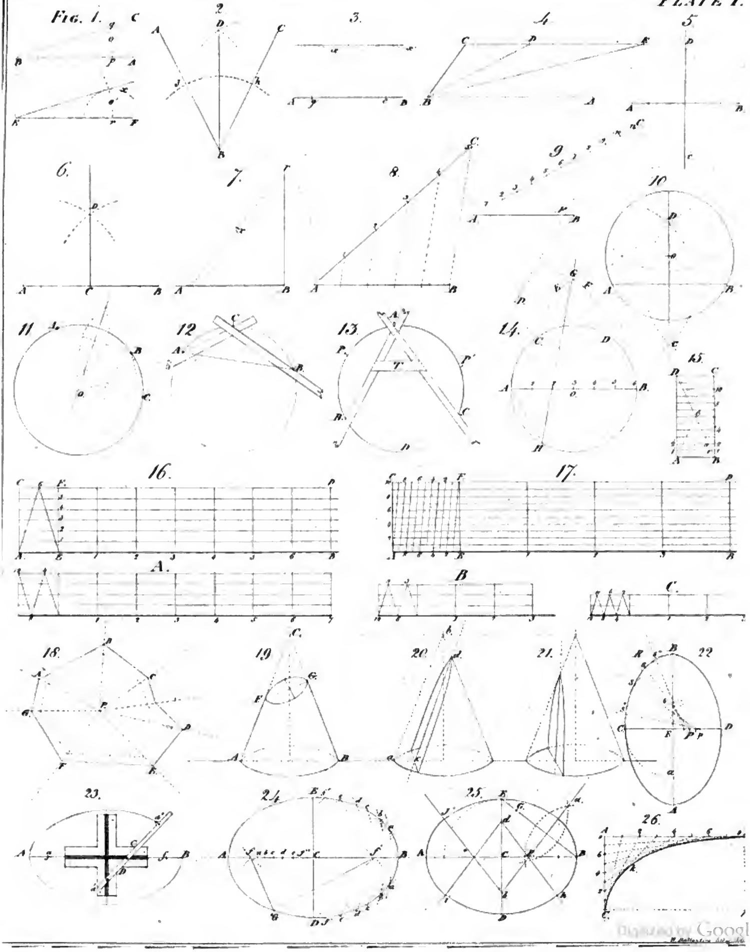
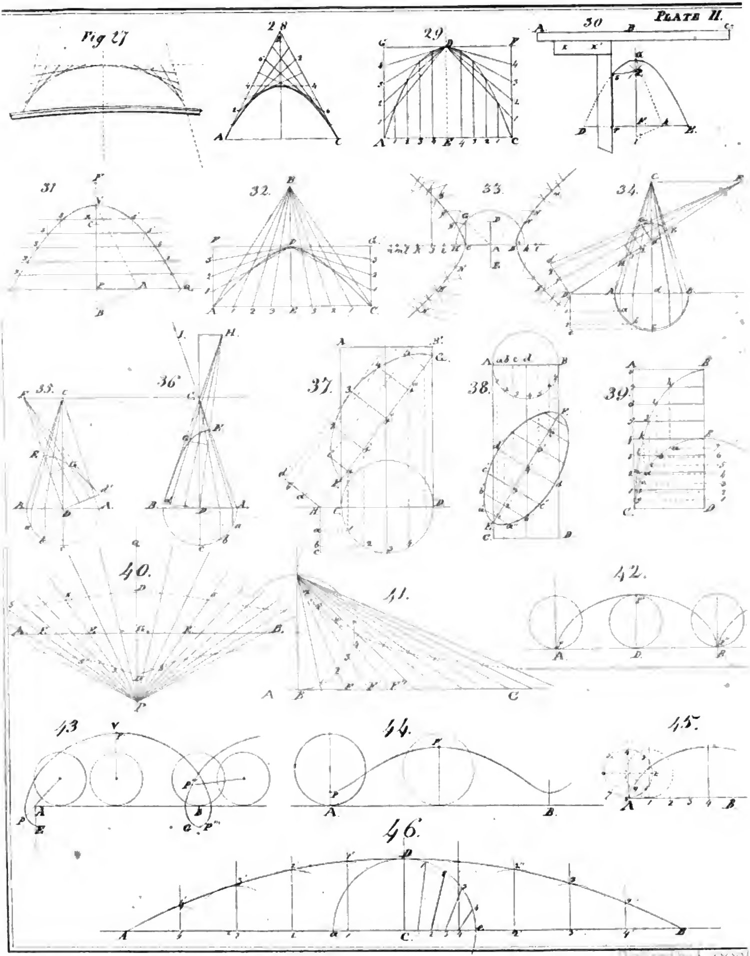


PLATE II.



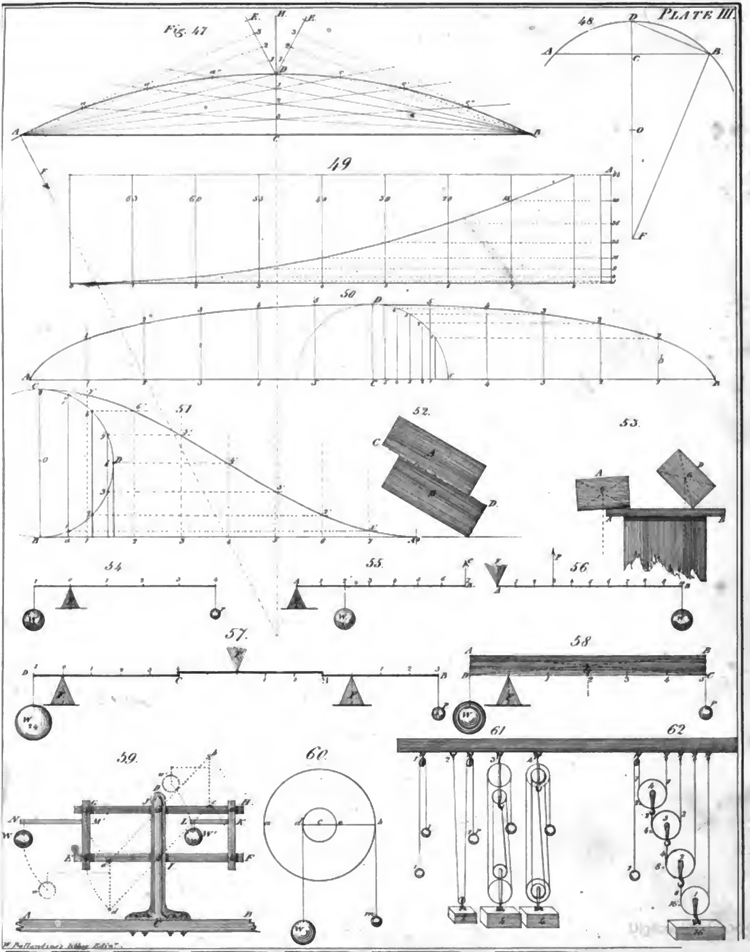


PLATE III.
Fig. 47
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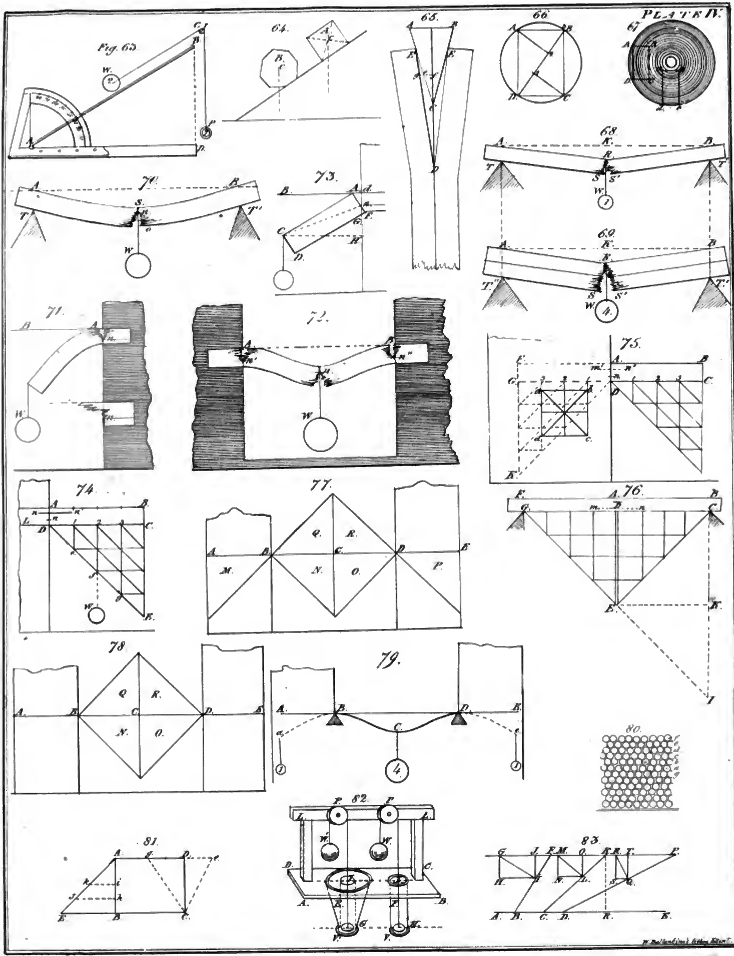
PLATE IV.
Fig. 63.
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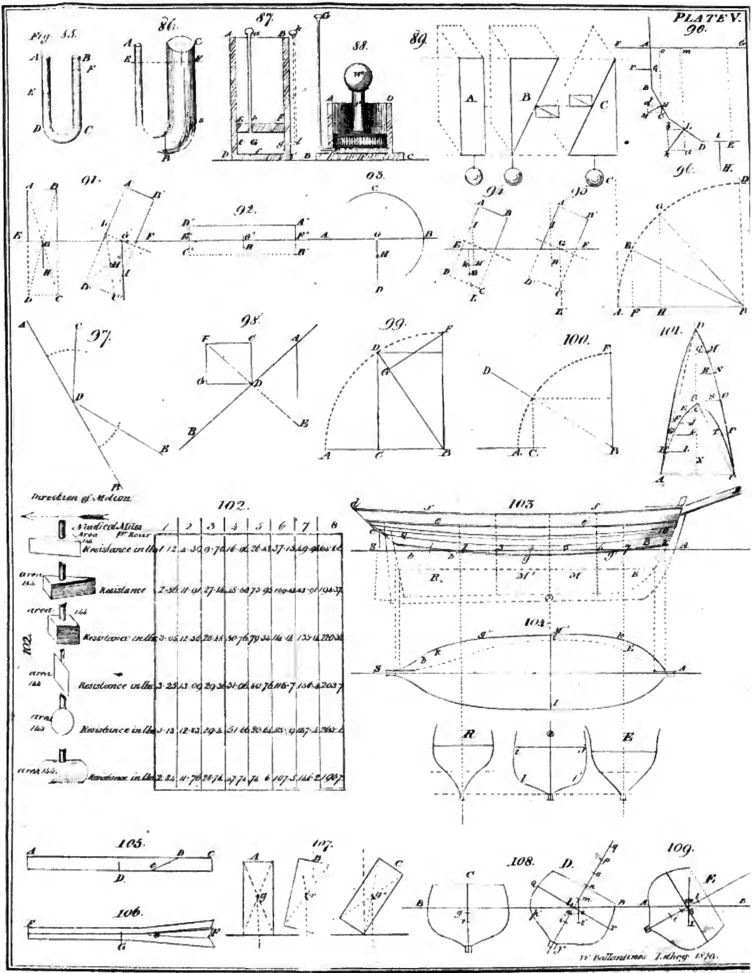

	1	2	3	4	5	6	7	8
Area 144. Resistance in lbs.	1·12	4·30	9·70	16·[illegible]	26·[illegible]	37·13	[illegible]	[illegible]
Area 144. Resistance	2·56	11·[illegible]	27·[illegible]	[illegible]·60	73·95	100·[illegible]	[illegible]·91	194·37
Area 144. Resistance in lbs.	3·05	12·36	28·[illegible]	50·76	79·30	116·[illegible]	135·[illegible]	220·[illegible]
Area 144. Resistance in lbs.	3·25	13·09	29·36	51·06	80·76	116·7	156·4	203·7
Area 144. Resistance in lbs.	3·13	12·53	29·2	51·66	80·66	115·9	157·3	[illegible]
Area 144. Resistance in lbs.	2·86	11·76	28·74	47·74	74·6	107·5	146·2	190·7

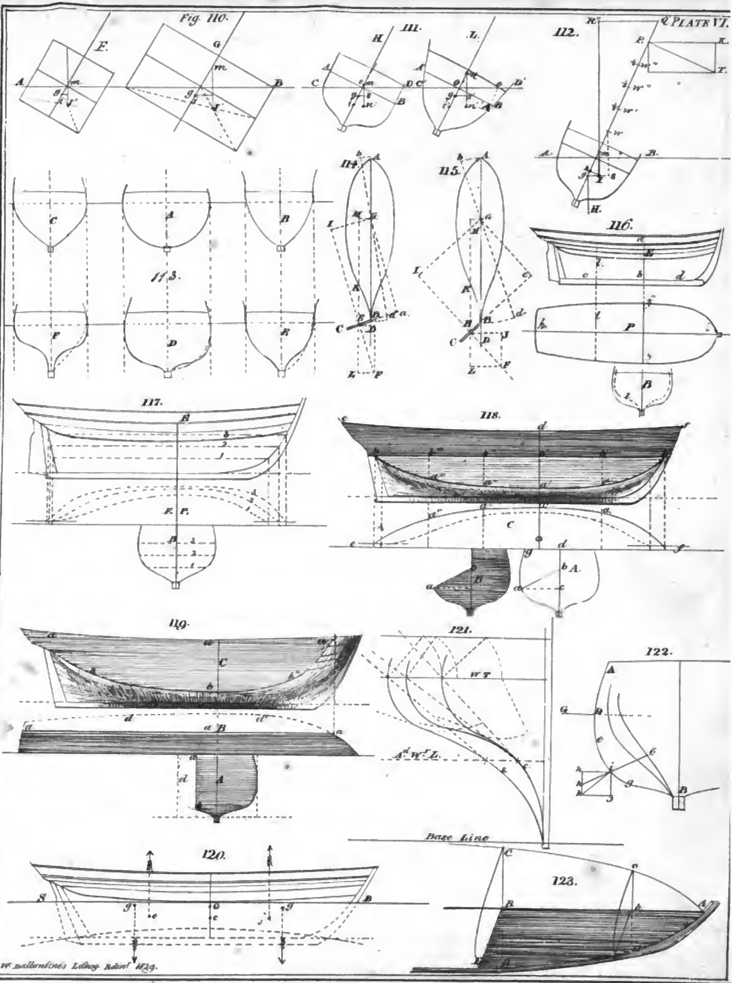
PLATE VI.
Fig. 110.
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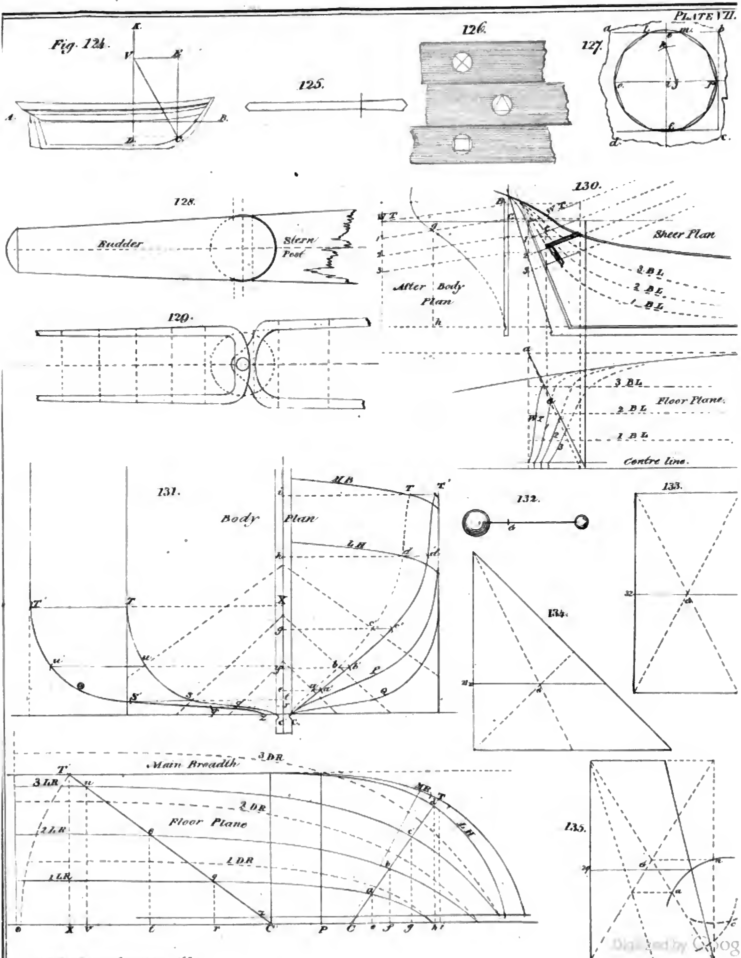
Base Line

PLATE VII.



W. Ballantine's Lithog. Edinr. 1829.

PLATE VIII.

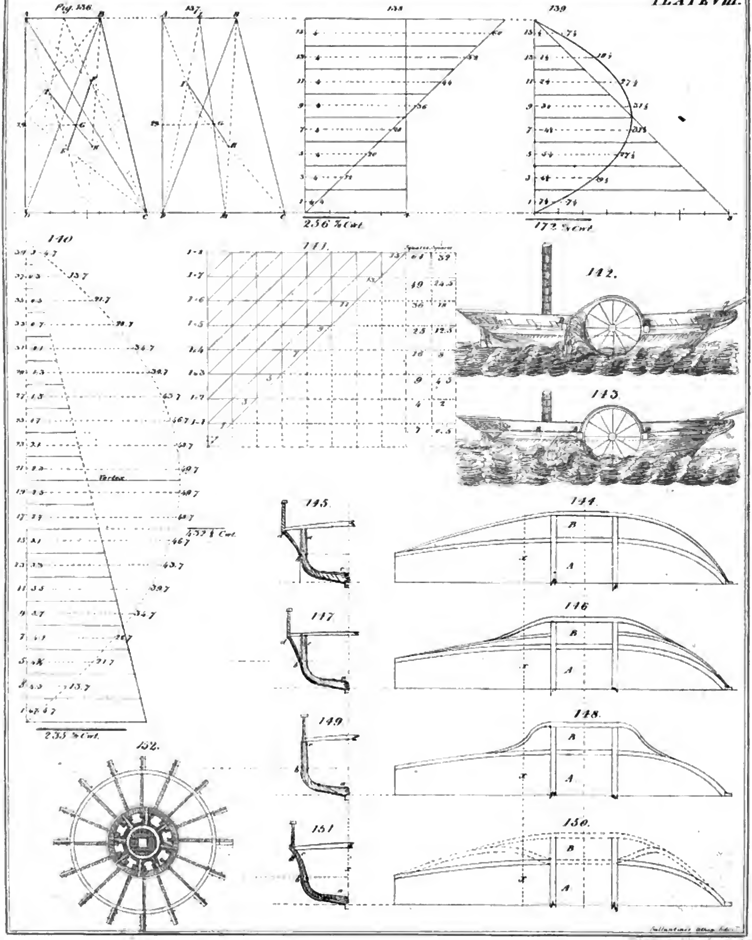


Fig. 136
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